Massachusetts' North Shore
Wetlands Assessment Project:

Transferring a Wetland Assessment Method to the North Coastal and Ipswich River Watersheds

February 2003

Prepared by:
Massachusetts Office of Coastal Zone Management

CZM

Prepared for:
Massachusetts Department of Environmental Protection
and
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1. Introduction

Project Goal

The fundamental purpose of the North Shore Wetland Assessment Project was to transfer the wetland assessment approach and methodologies conducted in the Waquoit Bay watershed pilot project from 1995 to1997. The Waquoit pilot project enabled investigators from Massachusetts Office of Coastal Zone Management (CZM) [including the Massachusetts Bay National Estuary Program] and the University of Massachusetts (UMass) to pioneer innovative tools to aid in the assessment of wetland ecological integrity. The report from the pilot project, as referenced below, serves as a primary reference for this project.

Carlisle, B.K., A.L. Hicks, J.P. Smith, B.G. Largay, and S.R. Garcia. 1998. Wetland Ecological Integrity: An Assessment Approach. Boston, MA: Massachusetts Coastal Zone Management.

The report can be accessed on-line at: http://www.state.ma.us/czm/wetlandecologicalintegrity.pdf.

The North Shore Wetland Assessment Project was funded through a grant from the Massachusetts Department of Environmental Protection's Bureau of Resource Protection (MA/DEP/BRP). The grant program is authorized by the Federal Clean Water Act §104(b)(3), overseen by the US Environmental Protection Agency (USEPA). The project started in June 1997. Funds from the National Oceanic and Atmospheric Administration to CZM also supported work on this project.

This grant provided CZM and UMass investigators with the opportunity to transfer and further evaluate the Wetland Assessment Method developed in the Waquoit Bay pilot. The goal of this project was to take the pilot methodology and apply it to selected wetland study sites located in two coastal watersheds of Massachusetts—the Ipswich and the North Coastal. Through the transfer of the Wetland Assessment Method, investigators and the project manager would determine the successes, opportunities, problems, and difficulties in its continued application. Results from the Waquoit Bay pilot project indicated that the methodology had valuable potential to serve as an effective tool for state agencies and Basin Teams, local citizens, watershed associations, and municipal officials to evaluate wetlands for numerous purposes, including:

- inventory type applications for assessing the relative condition of wetlands in specific areas (such as towns or sub-watersheds),
- measuring and evaluating the success of wetland restoration or compensatory mitigation projects, and
- examining and quantifying the condition of wetlands over time.

Background

To date, much of the bio-assessment work in the United States has been associated with the development of biological water quality criteria for streams, rivers, and lakes (Gibson et al. 2000, Davis and Simon, 1994; Plafkin et al., 1989), though in the last 5 years there has been significant effort focused on wetlands (Danielson, 1998; US EPA 1996; Adamus, 1990). The national Biological Assessment of Wetlands Workgroup (BAWWG) was formed by the US EPA in 1997 with the objective of improving methods and programs to evaluate the biological integrity of wetlands (http://www.epa.gov/owow/wetlands/monitor/). BAWWG consists of wetland scientists from federal agencies, states, and universities. A New England derivative of BAWWG was organized in 1999 to focus on specific regional issues and to advance dialogue and coordination (http://www.epa.gov/region1/eco/wetland/index.html). The goal of wetland biological assessment (bio-assessment) is to evaluate a wetland's ability to support and maintain a balanced, adaptive community of organisms having a species composition, diversity, and functional organization comparable with that of minimally disturbed wetlands within a region.

In addition, since 1999, the review, evaluation, and discussion of standardized salt marsh survey protocols have been an area of focus for two regional forums: the Global Programme of Action/Coalition for the Gulf of Maine, coordinated by the Wells National Estuarine Research Reserve and the Great Marsh Working Group, coordinated by Massachusetts Audubon Society. Through these forums there has been active interaction and debate between researchers and investigators from state and federal agencies, universities, and regional nonprofits as to the most appropriate techniques and methods for surveying or monitoring salt marsh wetlands.

This document details the field sampling and data collection methods, data analysis, and results of wetland condition indicators: two biological assemblages (plants and macro-invertebrates), two rapid assessment tools, water chemistry measures, and a comprehensive characterization of stormwater discharges to 2 wetland study sites. Data sets are examined for relationships between indicators as well as association with human disturbance and land use. References and appendices are included.

In the transfer and evaluation of the CZM Wetland Assessment Method during the North Shore Project, many lessons were learned. This project was the second application of a new methodology, and it is to be expected that potential changes would be identified and recommended. The revisions to the Wetland Assessment Method proposed in this report will make the method more robust and responsive. They are based entirely on the judgment and opinions of the principal investigators and project manager. In some cases these revisions are significant—such as modifying the sampling method for plants—while in others the changes are minor adjustments—adding a new metric to the invertebrate protocol, for example. For each recommended change to the method as implemented in the Waquoit pilot project, there is a call-out box, explaining the nature of the revision and the rationale behind it.

2. The Wetland Assessment Method

The CZM Wetland Assessment Method is an approach to wetland assessment which combines field-based biological and chemical sampling with rapid assessment tools to produce a broad evaluation of the ecological condition of wetland study site. The field-based indicators utilized in this application of the Wetland Assessment Method include:

- Plants
- Aquatic macroinvertebrates
- Water chemistry

The rapid assessment tools utilized in the Wetland Assessment Method include:

- Land Use Index
- Habitat Assessment

Past studies in the assessment of biological integrity or water chemistry in water bodies have focused on a limited number of parameters or attributes that connect to a narrow range of perturbations. Recent approaches in biomonitoring and ecological investigations have incorporated methods that examine an array of parameters or variables and incorporate responses from as many ecosystem levels as possible. These methods are referred to as multi-metric approaches. *A metric is a parameter or variable that represents some feature, status, or attribute of biotic assemblage, chemical state, or physical condition that responds to disturbance.*

This Wetland Assessment Method relies on a multi-metric approach for analyzing and reporting biological data. Multi-metric analysis works in much of the same way as other well-known financial indices, such as the Dow Jones industrial average or the S&P 500. These indices combine several financial measures to assess the performance of the stock market or a set of similar investment opportunities. In a multi-metric approach, several different metrics are chosen in order to effectively capture and integrate information from individual, population, guild, community, and ecosystem levels and processes. Metrics are selected based on literature reviews, historical data, and professional knowledge. The following are some examples of metric types from the different indicator protocols contained in the Wetland Assessment Method:

PROTOCOL	METRIC TYPE	SUMMARY
Biological	Taxa Richness	The diversity of species (taxa) from a population
Biological	Invasive Species	Proportionate composition of invasive species
Physical	Hydrology	Similarities and differences in hydroperiod
Chemical	Ortho-Phosphates	Mean concentration of limiting nutrient in water

The quantitative output from each metric is then combined to produce an index. *An index is the aggregate of metric scores that serves to summarize the biological, chemical, or physical condition.* The use of a control data set, or reference condition, with which to compare other sites in question is a fundamental tenant of a multi-metric assessment approach. *The reference condition establishes the basis for making comparisons and for detecting impairments; it should be applicable to study sites on a* *regional scale.* The reference condition should be representative of sites at which minimal impacts exist (i.e., relatively pristine) or sites with existing conditions that are deemed to be the best attainable for a given region (i.e., heavily urbanized or agricultural). Reference conditions may be established by several means: the collection of *in situ* data, the use of historical data, employing a simulation model, or expert or best professional opinion.

The integration of various ecosystem level attributes is what gives the multi-metric approach its strength. The multi-metric approach is able to pick up perturbations that a more narrowly defined study may not; such an approach is also able to minimize weaknesses or variability of a single metric through the synthesis of the total array of metrics. Over the past decade, multi-metric approaches have been widely utilized for biological surveys of lakes, streams, and rivers but have not been adequately explored for their use in wetland ecological assessments. Several recent efforts, such as the Waquoit Bay pilot project, have emerged to adapt current methods and develop new techniques. Each new application of these wetland assessment approaches provides an opportunity for testing and refinement.

3. Study Area

The project study area was the North Coastal and the Ipswich River watersheds in northeastern Massachusetts. The region is characterized by irregular-shaped peninsulas and rocky shorelines in the southern portion, and vast salt marshes and barrier beach systems in the northern area. The North Coastal and Ipswich River watersheds' geology is characterized by bedrock dominated geology and the hydrology is predominately driven by surface water. Land cover and use in the watershed is varied, and is best characterized as dominated by mixed deciduous forest; moderate to dense residential, urban, and commercial areas; and isolated areas of industry, agriculture, transportation, and commercial/industrial.

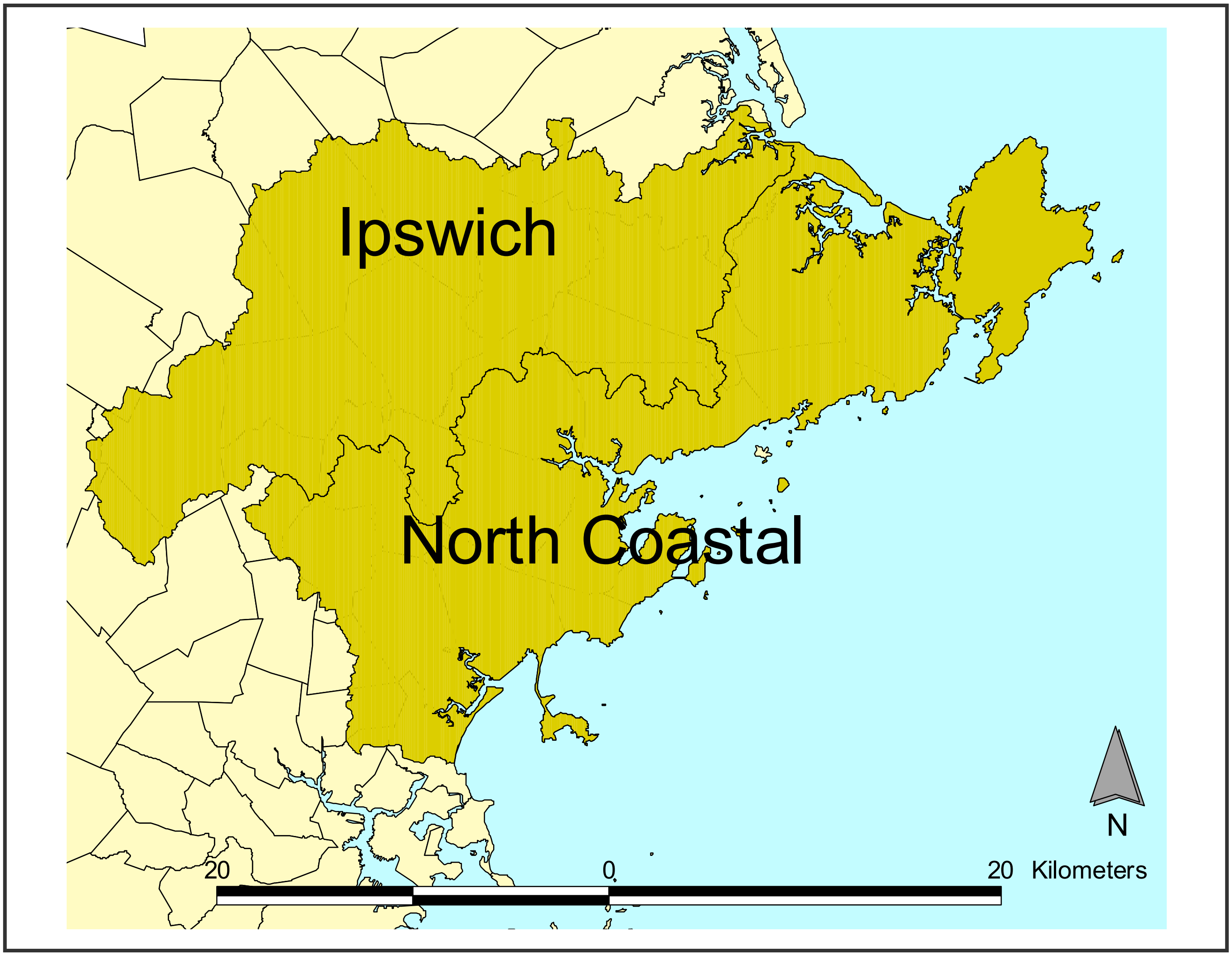

Figure 1. Map of the North Coastal and Ipswich River watersheds

4. Study Sites

Based initially on remote sensing from 1:12,000 color infrared photography obtained from the Massachusetts Department of Environmental Protection's Wetland Conservancy Program and on USGS topographical quads, a list of candidate sites was developed. The candidate wetland study sites for this project were chosen to be representative of two particular hydrogeomorphic types of wetlands in these coastal watersheds: depressional freshwater and tidal salt marsh. Sites were also selected to capture a range—or gradient—of surrounding land use types and intensity (see Table 1 and Table 2).

After the candidate site list was developed, project staff visited each one to confirm actual conditions of wetland type, location, accessibility, and surrounding land use and other site settings. The list was reduced based on these factors and the project staff then proceeded to obtain landowner permission for the work. Once landowner permission was acquired, the final study sites were established.

For both the freshwater wetland group and the salt marsh group, reference wetlands, or controls, were carefully selected. These reference sites were characterized as having only natural land cover and low-impact land use (recreation: walking trails and/or fire roads) within a 1000 meter zone. The four reference sites, IWS and TAS for the freshwater group and ICB and ECR for the tidal wetland group, were appraised to be wetlands that have been largely unaffected by anthropogenic activities and have land uses with low levels of human activity within their 1000 m buffer zone. Study sites had various human land uses within the 1000 m zone, including seven sites with direct storm drain discharges. Figure 2 displays the locations of the freshwater sites, and Figure 3 does the same for the salt marsh sites.

Table 1. Freshwater sites

Study Site	Watershed	Class	Cover Type	Land Use
IWS	Ipswich	Isolated depressional	Emergent Shrub	Reference: State conservation land
TAS	Ipswich	Riparian depressional	Emergent Shrub	Reference: Private nonprofit conservation land
IWN	Ipswich	Isolated depressional	Emergent Shrub	Town road, residential development, stormdrain
TCS	Ipswich	Riparian depressional	Emergent Shrub	Residential development, town road
BCH	North Coastal	Isolated depressional	Emergent Shrub	Industrial park, Impervious areas, stormdrains
BTC	North Coastal	Riparian depressional	Emergent Shrub	Residential development, impervious areas, stormdrain
DTS	North Coastal	Isolated depressional	Emergent Shrub	School, residential development, impervious areas

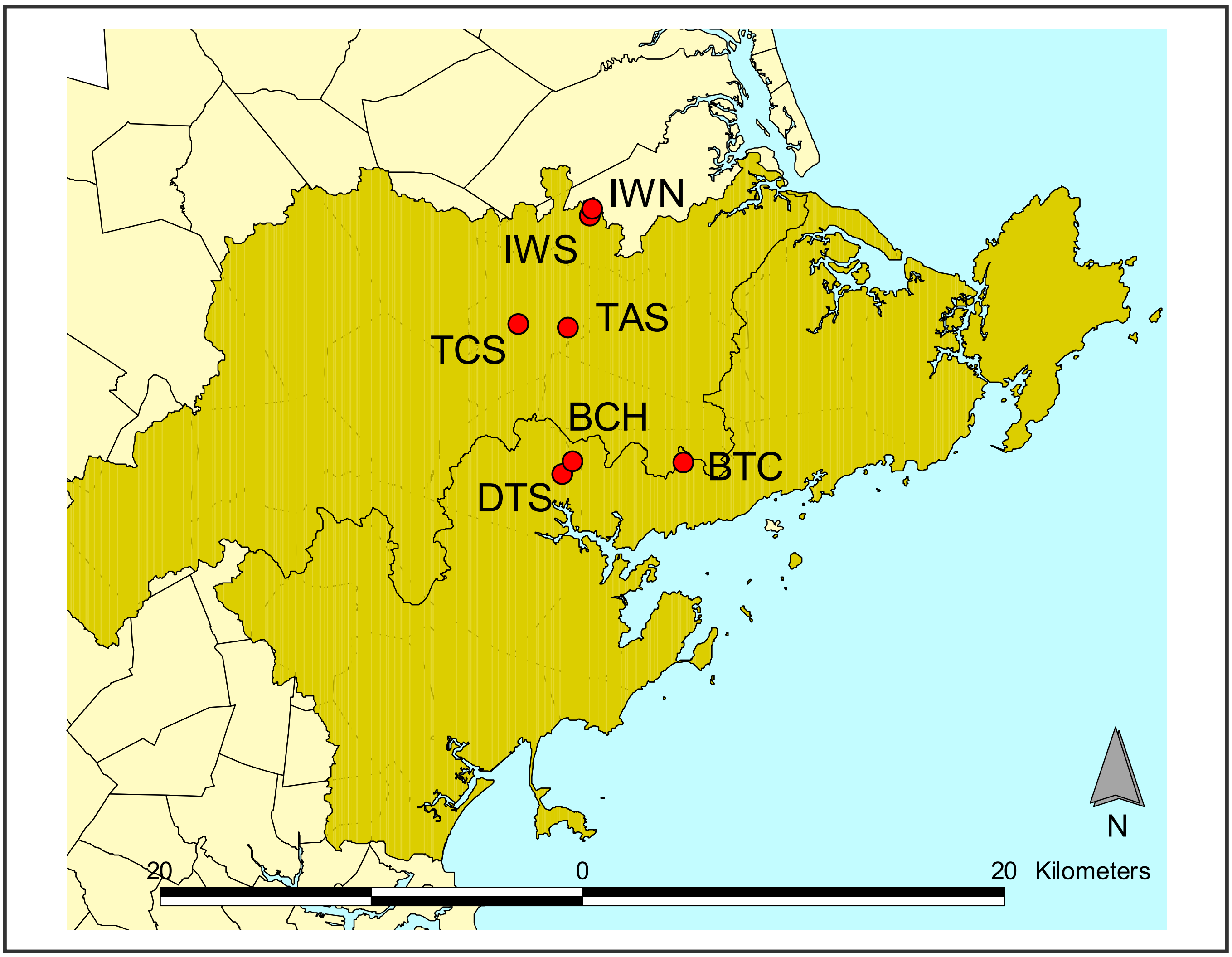

Figure 2. Map of freshwater wetland study sites

Table 2. Salt marsh sites

Study Site	Watershed	Class	Cover Type	Land Use
ICB	North Coastal	Salt marsh: barrier beach	Emergent	Reference: Private nonprofit conservation land
ECR	North Coastal	Salt marsh: estuarine fringe	Emergent	Reference: Private nonprofit conservation land
GGH	North Coastal	Salt marsh: estuarine fringe	Emergent	Residential development, impervious areas, stormdrains
IPB	Ipswich	Salt marsh: barrier beach/headland	Emergent	Residential development, impervious areas, stormdrain
ETC	North Coastal	Salt marsh: estuarine fringe	Emergent	Residential development, commercial area
ECP	North Coastal	Salt marsh: headland	Emergent	Residential development, impervious areas
DWR	North Coastal	Salt marsh: estuarine fringe	Emergent	Commercial area, residential development, stormdrains

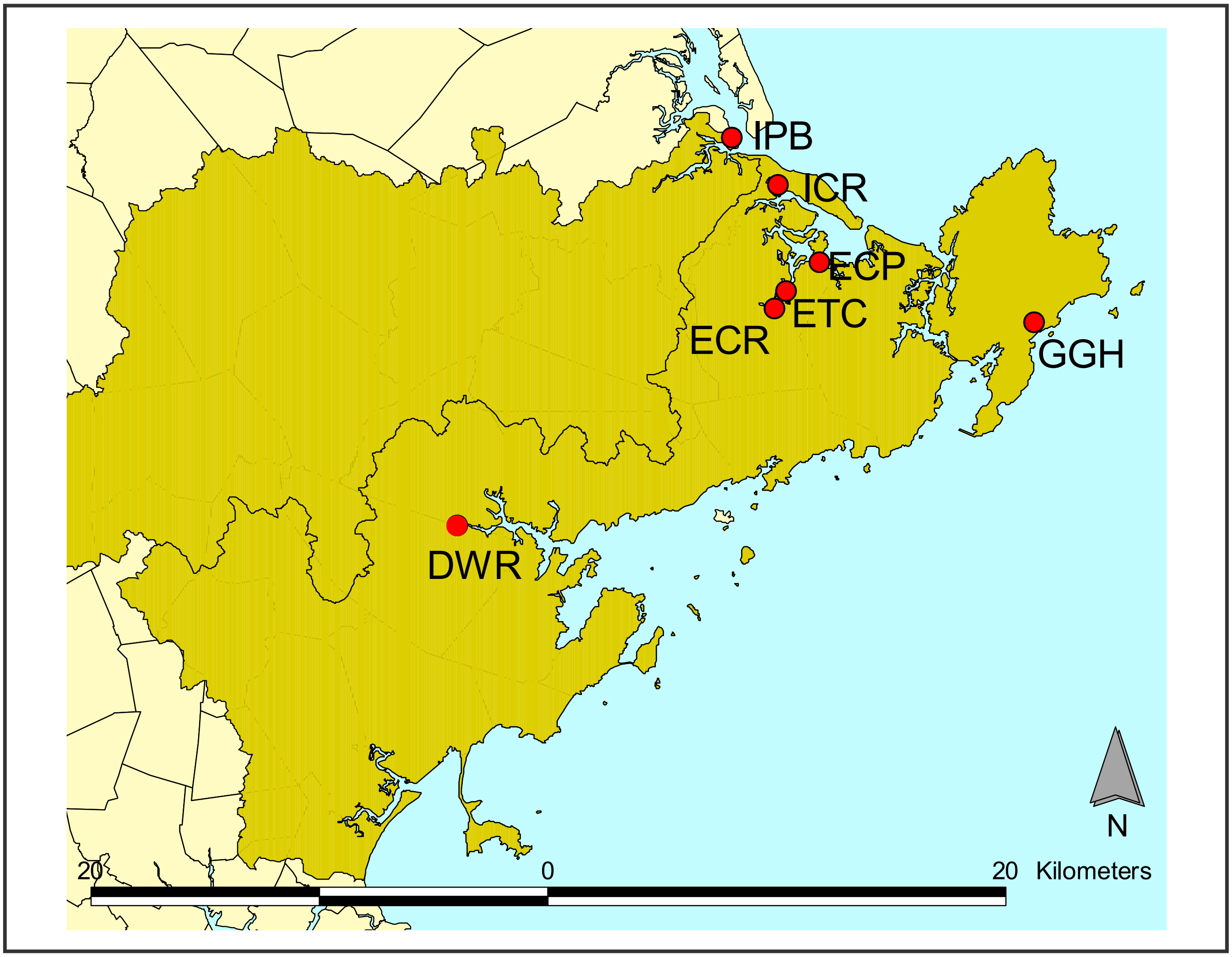

Figure 3. Map of salt marsh study sites

Freshwater Sites

Seven freshwater sites were selected throughout the North Coastal and Ipswich River watersheds. A brief description of each site follows.

IWS

One of two reference sites for the freshwater group, Ipswich Willowdale South (IWS) is a freshwater wetland located in the northern portion of Massachusetts' Willowdale State Forest. Approximately 7,043 m^2, IWS is an isolated depressional wetland with dominant plants cover of *Cephalnathus occidentalis* and *Dulichium arundinaceum*. Isolated depressional wetlands are located in depressions in the landscape and are influenced primarily by groundwater levels, though some may have intermittent inlets and/or outlets. Though another wetland unit (study site IWN)--just to the north of this site--is affected by stormwater discharge from a roadway and large residential development, this reference site is well buffered from that land use. Surrounded by deciduous forest, other wetlands, and trails, IWS has only low-intensity land use. Figure 4.

TAS

Topsfield Audubon Sanctuary (TAS) is the second reference site of the freshwater group. TAS is a 41,190 m^2 riverine depressional wetland. Riverine depressional wetland types differ from riverine fringe (or bordering wetlands) in that they are characterized by discernable depressions in the landscape and are associated with smaller order or intermittent streams. TAS is located in the floodplain of the Ipswich River, though its hydrology is dominated by groundwater levels and the flows of a very small, intermittent stream. On large overbank events (> 5 year), TAS will be inundated by Ipswich River flood waters. TAS is dominated by *Acer rubrum* (saplings), *Impatiens capensis*, *Rhamnus frangula*, and *Rosa palustris*. Figure 5.

IWN

Located just to the north of reference site IWS, study site Ipswich Willowdale North (IWN) is a 17,690m^2 depressional freshwater wetland in the very northern portion of Willowdale State Forest. While the site itself is within state conservation land, the proximate land use includes a large residential subdivision, Linebrook Road, and two direct, untreated stormdrain discharges. The dominant plants at IWS are *Typha latifolia* and *Lythrum salicaria*. Figure 4.

TCS

The freshwater wetland at Topsfield Central Street (TCS) is a 3,957 m^2 riverine depressional wetland. Riverine depressional wetlands are characterized in the description for reference site TAS. Study site TCS has the following land uses within its 100 m buffer zone: residential development, commercial development, and a paved stormwater swale from Central Street. Dominant plants at this site includes *Lythrum salicaria*, *Impatiens capensis*, and *Rhamnus frangula*. Figure 6.

BCH
Study site Beverly Cherry Hill (BCH) is a 8,635 m^2 isolated depressional wetland located at Cherry Hill Industrial Park in Beverly and Danvers. BCH is surrounded on all sides by industrial land use types—both active production industry and industrial office park. Three separate direct, untreated stormdrains discharge to BCH. *Typha angustifolia*, *Lythrum salicaria*, and *Onoclea sensibilis* comprise the dominant vegetation at this site. Figure 7.

BTC
Another riverine depressional site, Beverly Thoreau Circle (BTC) is a small, 1,683 m^2 freshwater wetland. BTC is surrounded on all sides by residential land use and on its southern side by Rt. 22. BTC has a direct, untreated stormwater discharge on its western side. Dominant vegetation is *Calmagrostis canadensis*, *Lythrum salicaria*, *Polygonum sagittatum*, and *Scirpus cyperinus*. Figure 8.

DTS
The isolated depressional wetland at Danvers Thorpe School (DTS) is the last freshwater wetland study site in this group. This 4,783 m^2 site is surrounded by residential development, institutional land use (school), and parking lots and access roadways. *Lythrum salicaria* and *Typha angustifolia* dominate the plant communities at this site. Figure 9.

Salt Marsh Sites

Seven salt marsh sites were selected throughout the North Coastal and Ipswich River watersheds. A brief description of each site follows.

ICB

The Trustees of Reservations conservation land at Crane's Beach in Ipswich represents one of several large (100+ acres) salt marsh areas preserved and protected on the North Shore. Ipswich Crane's Beach (ICB) is one of two reference sites for the salt marsh study group. The site is large, 270,208 m^2, and is surrounded by large areas of open space and small sections of transportation: there is a narrow, two lane road for beach access to the north and a single lane dirt road to the east. Dominant plants are *Spartina patens*, *Spartina alterniflora*, and *Distichlis patens*. Figure 10.

ECR

The Essex County Greenbelt owns vast amounts of conservation land throughout Essex County. At their headquarters in the town of Essex at Cox Reservation (ECR) the Greenbelt owns a large salt marsh area on part of the Essex River estuary. This expansive fringing salt marsh was selected as the second salt marsh group reference site. Land use surrounding ECR includes open space, low density residential development, and a small section of transportation (60 meters of Rt. 133). ECR is also a large site, 152,030 m^2. *Spartina patens*, *Distichlis spicata*, and *Juncus gerardii* comprise the dominant species of the mostly high marsh community. Figure 11.

GGH

The salt marsh site near Good Harbor Beach in Gloucester (GGH) on the north side of Thatcher Road (Rt. 127A) is one of the many study sites with direct, untreated stormwater discharges. Land use within the site's 100 m buffer zone includes low, medium, and heavy density residential development; transportation (including Rt. 127A and Witham Rd.); and open space. The site is 97,472 m^2 and dominant plant species include *Spartina patens*, *Juncus gerardii*, *Phragmites australis*, and *Agropyrens pungens*. Figure 12.

IPB

Small in comparison at 24,286 m^2, the salt marsh at Ipswich Pavillion Beach (IPB) is surrounded by medium and heavy density residential development from Great and Little Necks. Transportation land use from Little Neck Rd. contributes direct, untreated stormwater through a drain on the northern side of the marsh. *Spartina alterniflora*, *Spartina patens*, *Phragmites australis*, and *Distichlis spicata* make up the dominant plant cover. Figure 13.

ETC

Located in the middle of Essex town center (ETC) is a 64,650 m^2 expanse of salt marsh fringing the Essex River estuary. Land use is dominated by medium density residential development with areas of transportation (Rt. 133 and Water St.), commercial, and limited open space. This is one of several areas in Essex where failing and substandard on-site septic systems are contributing contaminated discharges to ditch drainages. ETC is dominated by *Spartina patens*, *Spartina alterniflora*, *Phragmites australis*, and *Distichlis spicata*. Figure 14.

ECP

Another site in Essex surrounded by medium to heavy density residential development is the salt marsh at Conomo Point (ECP). The pocket marsh is 54,197 m^2 and dominated by *Spartina alterniflora*, *Spartina patens*, and *Juncus gerardii*. Soils on Conomo Point are dominated by bedrock and many on-site septic systems here are substandard. Figure 15.

DWR

The fringe salt marsh at the head of the estuarine section Danvers Waters River (DWR) is the last study site, 64,956 m^2. The land use in the buffer zone of DWR is dominated by commercial activity, with shopping centers and malls, car dealers, hotels, restaurants, and a gas station. The total amount of impervious surface within this area is significant. Other land uses include transportation (Rt. 128, Rt. 114, and Rt. 107) and medium density residential. Multiple direct, untreated stormwater discharges are present at this site. Plants are dominated by *Spartina patens*, *Juncus gerardii*, *Distichlis spicata*, and *Phragmites australis*. Figure 16.

Recommendation 1: Establish consistent evaluation area

For the Waquoit Bay pilot and for this North Shore transfer project, the entire wetland site was considered as the evaluation area. Both the rapid assessment and the field-based indicator methods utilized the entire wetland. For the following reasons, this practice was problematic:

- Sites had large variability in size,
- Very large wetlands were not selected due to the logistical difficulty for many aspects of assessment,
- Only some part of the site was affected by the proximate land use/disturbance, and
- Larger sites required much more time and resources to survey.

After further evaluation and the discussion amongst the principal investigators, delineating a subsection of the wetland to be studied (Evaluation Area) is recommended in order to :

(1) Create more uniform study site sizes in order to increase comparability and decease size as a variable.
(2) Select the sub-area of the site most affected by (or closest to the disturbance(s)).
(3) Allow evaluators to examine subsections of larger wetlands that would have been unfeasible under the former method.
(4) Reduce the time required to survey sites.

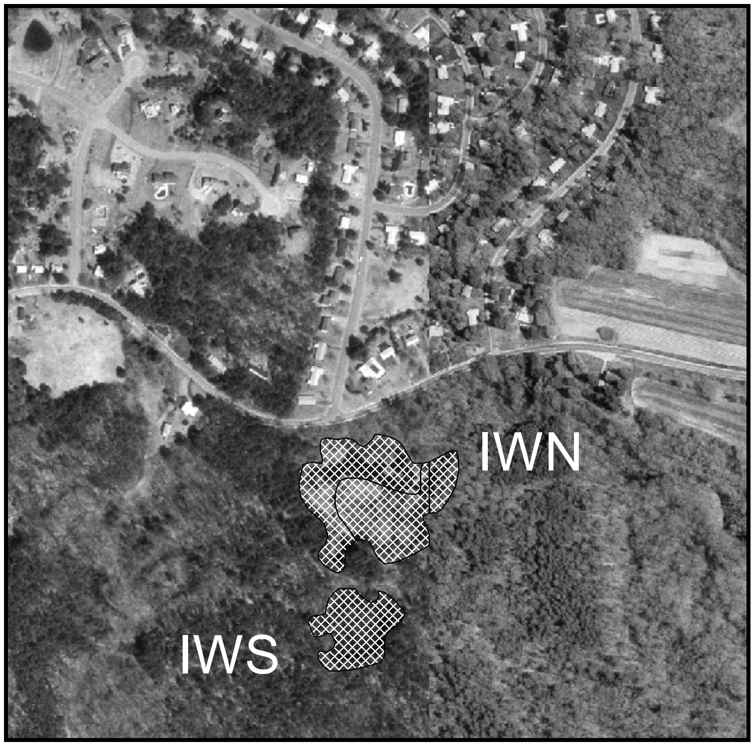

Figure 4. IWS and IWN

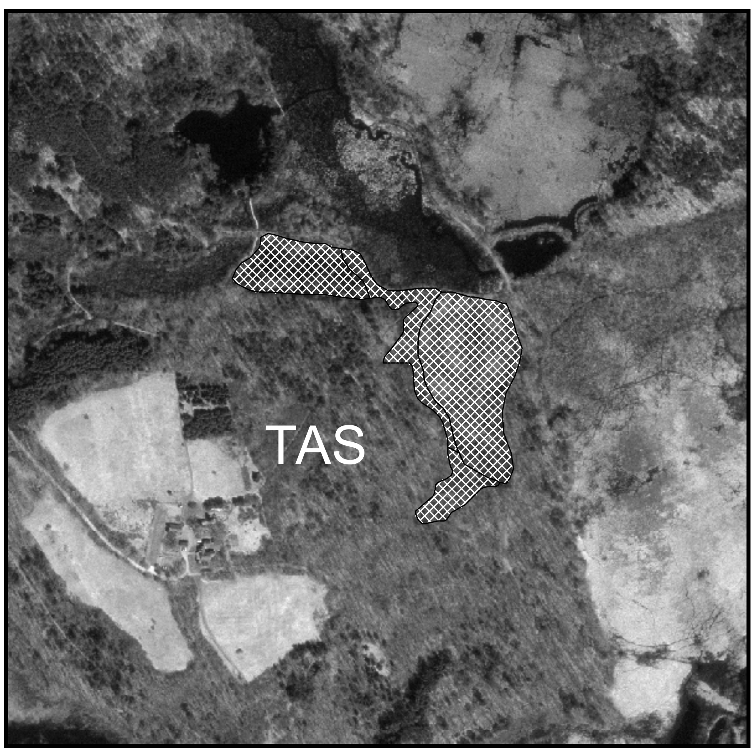

Figure 5. TAS

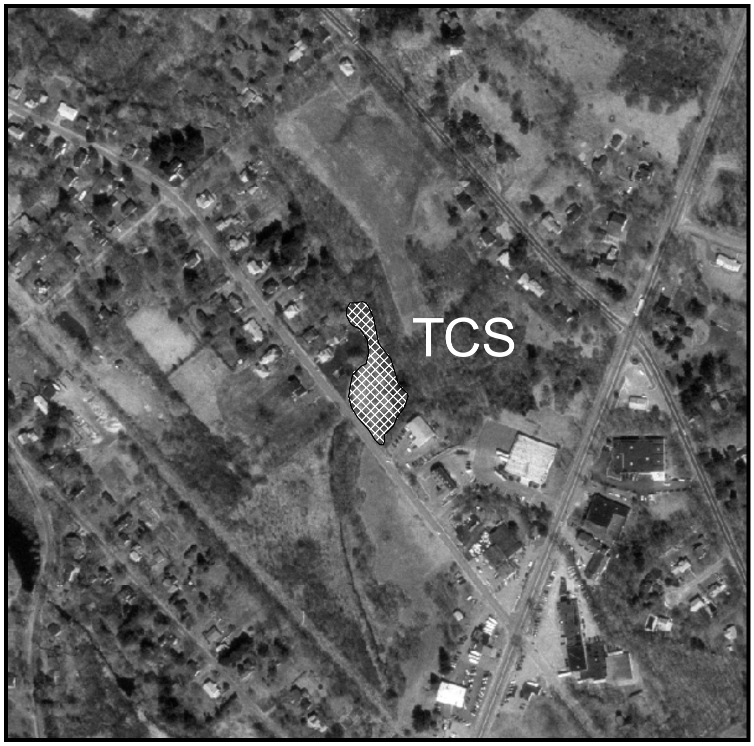

Figure 6. TCS

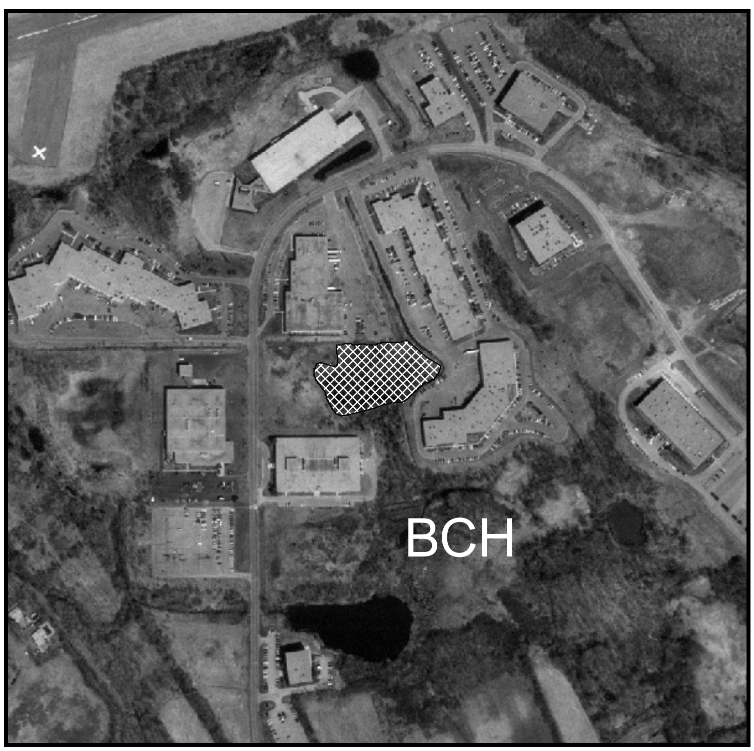

Figure 7. BCH

Figure 8. BTC

Figure 9. DTS

Figure 10. ICB

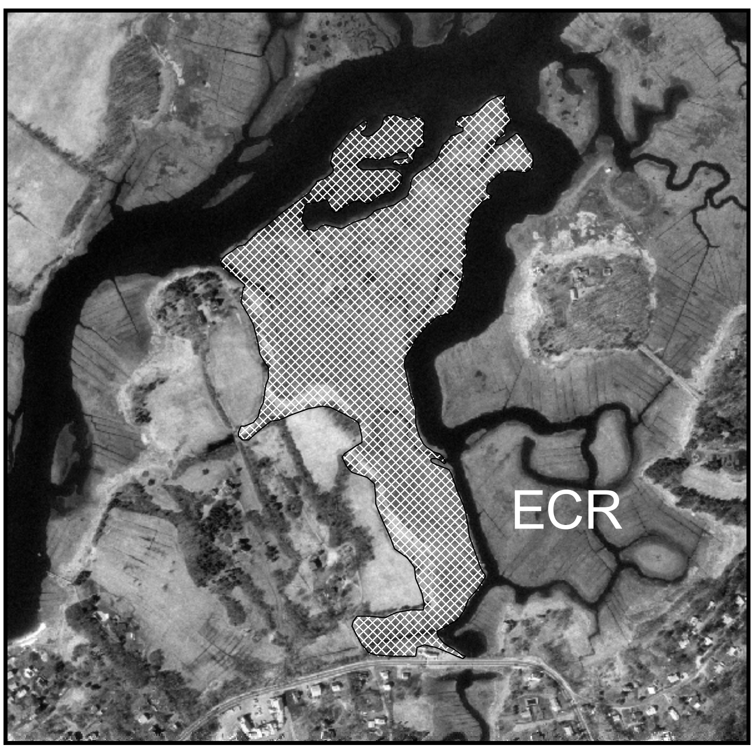

Figure 11. ECR

Figure 12. GGH

Figure 13. IPB

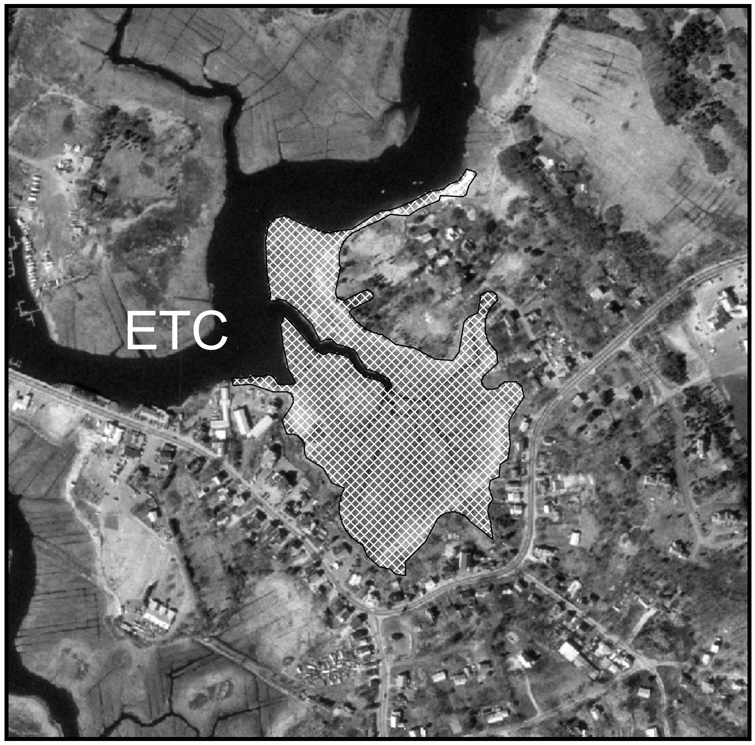

Figure 14. ETC

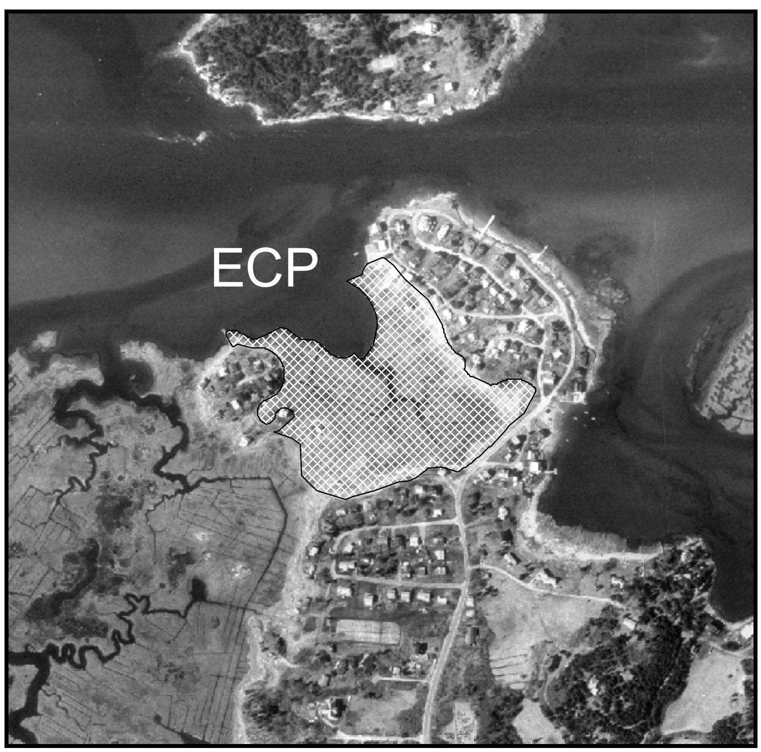

Figure 15. ECP

Figure 16. DWR

5. Rapid Assessment Methods

The development and availability of rapid assessment techniques allows investigators to utilize existing information and basic field-based wetland and landscape observations to derive a generalized estimate of wetland conditions. These rapid techniques can be highly useful in that they can be applied very quickly and by most field personnel (given adequate guidance), and they are inexpensive. Currently, several rapid assessment methods are used in lieu of more intensive field-based assessments for state and federal wetland regulatory and restoration programs. In the Wetland Assessment Method, rapid assessments serve to complement the field-based ecological indicators by aggregating basic information on wetland and landscape conditions--a necessary step for the data analysis and diagnosis of impairment causes. In addition, rapid assessment methods represent options for groups or individuals who lack sufficient resources to engage in more intensive, field-based wetland evaluation.

Measuring impact on wetlands from cumulative nonpoint source (NPS) pollution and hydrological alterations requires a landscape approach. Wetlands need to be viewed within the context of a larger ecosystem, not just as black boxes. In such an approach, four groups of factors could be considered: the source of the impact (the drainage basin and the immediate surrounding landscape); the nature of the wetland as a sink (the characteristics of the wetland and how effectively it can mitigate impact); the logical geographic scale for planning and management (wetland, surrounding landscape, sub-drainage basin, whole watershed); and finally the biological integrity of the wetland.

Land Use Index

Developed as a specific product of the wetland assessment pilot, the Land Use Index (LUI) was created in an attempt to quantify human disturbance to an given wetland (or other aquatic resource). It was developed to account for potential NPS pollutant contributions, physical alterations, and other stressors from surrounding land uses and landscape conditions. Due to the high variability in land use patterns and landscape characteristics, different wetland areas are subject to different levels of disturbance from human sources. The LUI results serve to provide a robust index of a wetland's relative susceptibility to human disturbance based on surrounding land use and observed impacts.

Wetlands are typically located in low-lying areas of the landscape, causing them to act as receiving points for upland sources of sediment, nutrient, and other pollutants (Nixon, 1986). Although some aquatic resources, such as types of wetlands, are able to perform water quality-related functions, such as sediment trapping and nutrient uptake or transformation, pollutant loads entering these resources may actually exceed its capacity to store, absorb, or transform them (Whigham, et al., 1988). In addition, these pollutants may have adverse effects on other aquatic resource functions and conditions such as flood storage and desynchronization, wildlife habitat and vegetation, production export, recreation, and successional state (National Research Council, 1991).

As the type and intensity of proximate human land uses increases, the wetland area becomes subject to corresponding changes to its hydrology, nutrient and sediment regimes, and habitat quality. This compounding of insults to the natural ecological integrity of aquatic resources is referred to as cumulative impacts. The LUI is a method that can help to better gauge, estimate, and rank the relative potential for cumulative impacts. The LUI methodology has been developed and refined based on data and field observations, extensive literature review, and professional opinion. Because no two wetlands are the same, nor are any region's or area's land use patterns and characteristics, this method has incorporated procedures to normalize for important variables. In this perspective, it is important to state and clarify the central assumptions of this method.

The first assumption is that the state and condition of a 100 foot and a 100 meter buffer zone are primary factors affecting the outcome of this index. Multiple references substantiate the fact that for most wetlands and riparian areas, in terms of pollutant transport, an area larger than 100 feet must be considered (Desbonnet, et al., 1994). For wildlife habitat, an undisturbed area of 300 feet is considered generally protective of many wetland obligates, but not all.

The second assumption recognizes that the production, transport, and fate of pollutants is influenced by a number of determinants, including the nature and type of land use, the physical characteristics typical of certain land uses, hydrological patterns of the contribution area, and intercepting or attenuating conditions. Based on extensive literature (see References) and available data, generalized assumptions can be made about the relative contributions of pollutants from specific land uses. Intensive uses such as commercial areas (malls and urban centers, for example) produce more pollutants than low density residential uses. Similarly, different land uses are likely to cause different levels and types of disturbance. An active industrial site will, by nature, generate more pollution, noise, and physical debris than a suburban conservation area. Through the development of relative land use coefficients, this methodology has attempted to incorporate many of these variables into evaluation procedures.

The LUI scores for this project were computed through a combination of Geographic Information System (GIS) analysis—generating a quantitative output of land use and impervious area—and an on-site rapid assessment worksheet. The basic steps to compute the LUI are:

- Delineate the wetland study site and specific evaluation area;
- Isolate and classify surrounding land uses;
- Establish the 100 ft and the 100 m buffer zones;
- Compute areas of distinct land uses within the buffer zones;
- Multiply land use areas by land use coefficients (see Appendix A);
- Total results and divide by total area to generate the GIS score;
- Calculate percentage of 100 m buffer zone occupied by impervious surface;
- Assign impervious group score based on Table 3;

- Complete onsite LUI worksheet;
- Average GIS score, impervious score, and rapid onsite score to get final LUI score.

Table 3. LUI scores for six ranked groups of impervious area

% Impervious Area	Score
0-3	100.00
>3-7	80.00
>7-15	60.00
>15-30	40.00
>30-60	20.00
>60-100	0.00

The LUI scores for the study sites are presented below. The LUI scores are structured to indicate the relative amount and intensity of human disturbance around a given site. The Land Use Index scale is 1-100, with the higher scores indicating less human disturbance.

The Land Use Index scores for the seven freshwater and seven salt marsh study sites were derived according to the above methodology. The LUI scores for each site is listed in Tables 4 and 5 below.

Table 4. Land Use Index scores for freshwater sites

	IWS	TAS	IWN	TCS	BCH	BTC	DTS
LUI-100ft	100	100	99	80	71	58	80
LUI-100m	100	100	96	66	53	58	73
Rapid Assessment	99	98	79	74	72	77	80
Impervious Score	80	80	60	40	20	20	40
LUI Score	**95**	**94**	**83**	**65**	**54**	**53**	**68**

Table 5. Land Use Index scores for salt marsh sites

	ICB	ECR	GGH	IPB	ETC	ECP	DWR
LUI-100ft	100	89	92	63	80	73	88
LUI-100m	100	83	85	58	73	66	70
Rapid Assessment	88	88	66	71	66	71	73
Impervious Score	80	60	60	20	40	40	40
LUI Score	**92**	**80**	**75**	**53**	**65**	**62**	**68**

Recommendation 2: Change Land Use Index method

For the Waquoit Bay pilot project, the three zones that were evaluated for land use impacts were the wetland-only zone, 100 foot jurisdictional buffer zone, and a 100 meter buffer. Based on the analysis for this North Shore transfer project, abandoning the use of the wetland-only zone in the GIS-based analysis is recommended. Due to the accuracy and source data for the mapping of the land use data layers, a specific land use polygon was frequently mapped within the actual wetland area, when field verification and fine-scale remote sensing (1 meter orthophotos) indicated otherwise. Further evaluation of the contents and scoring of the field-based data sheet to ensure that the potential impacts to wetland study sites are adequately captured and score/values are appropriate is also recommended.

Habitat Assessment

The focus of the Habitat Assessment (HA) method is to provide contextual and supporting information for the aquatic macro-invertebrate indicator. It provides the necessary input on habitat integrity and quality for invertebrates, though it certainly has broad implications for other wetland biota. This HA method was adapted by A.L. Hicks (1996) from a protocol developed by Plafkin et al. (1989) and Florida DEP (1996).

For the HA method, two groups of criteria are utilized: surrounding landscape characteristics and onsite wetland features. For each site a HA worksheet is completed by trained project staff personnel at least one time during the growing season. The HA field forms are contained in Appendix B. The landscape level characteristics that are evaluated are: the dominant land uses; the amount of impervious cover within the local sub-drainage basin (wetland contribution area); the amount of natural vegetation within the local sub-drainage basin; the ratio between the size of the wetland and the size of the sub-drainage basin; and finally, the major sources of pollution. Using the HA field form, evaluators select from the scoring criteria columns (5-6, 3-4, 1-2, 0) the description that best describes the wetland for each indicator. Evaluators use best professional judgment when examining the wetland in order to assign the scoring criteria at the higher or lower end of the spectrum (i.e., 5 instead of a 6).

For freshwater wetlands, the onsite descriptors of habitat quality are: degree of water level fluctuation, nature of any outlet restriction, rate of sedimentation, nature of the wetland substrate, vegetation diversity, degree of buffering from impacts, the intensity of human activities within the wetland, and finally an assessment of the available food sources for aquatic invertebrates. Additional salt marsh descriptors include: littoral alterations, plant community types, tidal fluctuation, freshwater discharges, channelization, wave action, sediment type, and degree of impact from human activities. The use of Cowardin wetland classes are employed in the HA method. This system was develop by Cowardin et al. 1979 to identify wetlands by specific characterizations including vegetation, soils, hydrology, salinity, and others. The Cowardin system has been widely accepted as the current national standard for wetland classification (the basis for the National Wetlands Inventory, for example), though adaptations of the Cowardin system are currently underway to incorporate additional abiotic features such as landscape position and landform type (Tiner, 1997).

For this project, the HA was completed during May 1998. The results of the HA are displayed in Table 6. The output score is a relative ranking of habitat quality on a scale of 100. A score of >80 is indicative of healthy wetland habitat conditions. More discussion of the use and output scores of the HA method is contained in Section 8, Invertebrates.

Table 6. Habitat Assessment scores

Freshwater Sites	**IWS**	**TAS**	**IWN**	**TCS**	**BTC**	**BCH**	**DTS**
HA score	90	82	82	70	58	64	68
Salt Marsh Sites	**ICB**	**ECR**	**GGH**	**IPB**	**ETC**	**ECP**	**DWR**
HA score	80	73	70	70	58	62	55

<u>Recommendation 3: Change Habitat Assessment method</u>

As the landscape characterization component of the Habitat Assessment method is quite similar to, and in some ways replicates, the Land Use Index, this recommendation is to remove the landscape component from the HA. The HA method then will rely on the values generated by the Land Use Index for that landscape/land use influence. The focus of the HA method will be on wetland habitat and its ability to support macroinvertebrates and the additional trophic levels that depend on this energy source.

6. Plants

Method

The wetland vegetation investigations for this project required species identification and cover abundance assessment at all 14 wetland study sites. Cover data were collected during the middle of the growing season (late June to the middle of September). The vegetative cover abundance of the study sites was surveyed using plant community sampling protocols adapted from Tiner (1996) and Jackson (1995). A plot sampling method was utilized in this investigation. The plot sampling method produces a comprehensive species list and an accurate assessment of plant cover area, or abundance. Similar to a general observation method, evaluators first determined the community structure of the study site and the dominant species present. Next the cover area for each community was assessed and then randomized plots were established in each distinct vegetative community. If a random plot site occurred at the upland border where vegetation patterns were transitional, the plot was discarded and sited again. Plot size depended on the vegetative strata being assessed. The four strata groups are defined in Table 7.

Table 7. Wetland vegetation strata

Strata	Defined As	Plot Size
Trees	Diameter at breast height ≥ to 5 in. and 20 ft. or taller	30 ft. radius
Saplings	Diameter at breast height < 5 in and 20 ft. or taller	30 ft. radius
Shrubs	Woody plants less < 20 ft. tall	15 ft. radius
Herbs	Non-woody (herbaceous) plants	5 ft. radius

For trees, basal area for each tree was determined. Diameter at breast height (dbh) was measured with a diameter tape at a height of 4.5 ft. above the ground surface. Basal area (BA) was calculated using the formula: $BA = (3.1416) \times (dbh^2/4)$. Every plant present in the sampling plots was identified to species level. For each species in the sampling plot, cover area was estimated, compared to another evaluators' estimate and revised if necessary. Cover area estimates took into consideration the coverage of duff, leaves, bare ground, open water, and non-target vegetation (i.e., herbaceous species in a shrub plot), and cover estimates were revised accordingly. The surveys were completed between June 15 and September 15 1998.

Recommendation 4: Eliminate observation method for plants

For the Waquoit Bay pilot project, two sampling methods were utilized for wetland vegetation: the plot sampling method and the observation method. The observation method was only utilized when the sites were small (1-2 acres) and easily accessible (entire site walkable). In order to reduce variability and ensure comparability, the observation method has been abandoned. Only the plot sampling method should be utilized.

Recommendation 5: Improve consistency and statistical validity for plant survey method

In the community-based plot sampling survey technique of the Waquoit Bay pilot project and this transfer project, it became clear that while representative, the plot locations were not easily reproduced. In addition, there was not any clear standard protocol regarding the location of plots. New transect-based survey approaches should be examined, with some element of random plot generation and location to ensure statistical non-bias.

Data Analysis

A multi-metric approach, using the reference condition as the basis of comparison, was used to analyze the raw data, compile individual metric scores, and derive a final Plant Community Index (PCI). Throughout this study, the freshwater and the salt marsh sites were evaluated and compared separately. Data obtained from each study site were entered into computer spreadsheet files (Excel 97), compiled, and metrics were generated as described below. Statistical analysis was completed primarily by computer software (Excel 97). For each plot evaluated, percent cover always totaled 100, but, as explained above, this cover percentage often included the category called *other* (duff, leaves, bare ground, open water, and non-target vegetation types). Cover area percentages, or abundance values, were then adjusted to account for the percentage of wetland cover occupied by *other*. When the *other* value was removed, the remaining plant species coverage totaled 100.

For this investigation, a community-based assessment approach was employed. With this assessment method, individual vegetation species abundance values were adjusted according to the extent of each community in the wetland. This community-based approach results in a more accurate estimate of each species' relative abundance in the wetland, not just in the survey plot. After the abundance values were adjusted for community-weighting and for *other* coverage, total species lists were compiled. Each list includes the total wetland abundance value for each species at each wetland study site. From the total lists, each species was then assigned specific wetland vegetation attribute scores. Each wetland vegetation attribute and value is defined below. Appendix C contains the species list and the attribute scores.

- **Persistent Standing Litter**. A species with a positive persistent standing litter attribute has a significant part of its above-ground biomass that remains standing during the dormant period until next growing season. All shrubs and trees are persistent. Examples of emergent plants with persistent standing litter are: *Typha latifolia*, *Scirpus cyperinus*, and *Spirea tomentosa*. Species with persistent standing litter were assigned a score of 1; those that die back were assigned a 0. The attribute scores were based on literature, identification guides, and professional judgment.

- **Opportunistic**. A species with a positive opportunistic attribute is able to tolerate a wide range of habitat types and conditions and is therefore well adapted to thrive in a variety of conditions. Opportunistic species will pioneer disturbed areas as well as compete advantageously in altered sites. Examples of opportunistic species are: *Sparganium eurycarpon*, *Lysimachia terrestris*, and *Clethra alnifolia*. Opportunistic species were assigned a score of 1; others assigned a 0. The attribute scores were based on literature, identification guides, and professional judgment.

- **Invasive**. A species with a positive invasive attribute is defined as an aggressive colonizer of natural and disturbed areas, often forming extensive monocultural stands. Invasive species are frequently alien, or non-native. Examples of invasive species are: *Phragmites australis*, *Decodon verticilatus*, and *Toxicodentron radicans*. Invasive species were assigned a score of 1; others were assigned a 0. The attribute scores were based on literature, identification guides, and professional judgment.

- **Wetness**. A ranking of a species relative affinity to hydric (wet) conditions, this attribute is taken directly from the USFWS National List. Attributes range from obligate (wetland dependent) to upland, based on the median probability of a species occurrence in a wetland. Wetness scores were assigned according to this scale: Obligate = 1.00, FacWet+ = 0.91, FacWet = 0.82, FacWet- = 0.71, Fac+ = 0.60, Fac = 0.50, Fac- = 0.71, FacUp+ = 0.29, FacUp = 0.18, FacUp- = 0.09, Upland = 0.00.

- **Flood Tolerance**. A ranking of a species tolerance to relative lengths of inundation, this attribute ranges from intolerant to very high tolerance. Intolerant species are killed by less than 3 days of inundation in a growing season, while species with very high tolerance can withstand a full growing season of inundation. This attribute is used only for freshwater species. Flood tolerance scores were assigned according to this scale: Very High = 1.00, High = 0.80, Medium = 0.60, Low = 0.40, Intolerant = 0.20. The values for this attribute were adapted from the New England Institute for Environmental Studies Plant Community Indicator Database (Michner,1990).

- **Salinity Tolerance**. A ranking of a species' tolerance to saline conditions, this attribute range from intolerant to very high tolerance. Intolerant species will not survive salt water exposure, including occasional ocean spray. Species with very high tolerance will survive in tidal areas with twice daily inundation of salt water. This attribute is used only for salt marsh wetland species. Salinity tolerance scores were assigned according to this scale: Very High = 1.00, High = 0.80, Medium = 0.60, Low = 0.40, Intolerant = 0.20. The values for this attribute were adapted the New England Institute for Environmental Studies Plant Community Indicator Database (Michner,1990).

- **Nutrient Status**. In this ranking, a species' affinity for nutrient availabilities is quantified. Attributes range from species generally occurring in areas with low nutrient availability (as in bogs and isolated wetlands) to those species occurring in areas with disturbances or enrichment from fertilizer or wastewater. Nutrient status scores were assigned according to this scale: Bogs, lowest nutrients = 0.12; Sands, low nutrients = 0.23; Acid woods, till, and sandy loam = 0.34; Alluvial acid soils, enriched by flood deposits = 0.45; Sweet soils in calcareous areas = 0.56; Alluvial sweet soils = 0.67; Somewhat disturbed or partly enriched soils = 0.78; Disturbed or enriched soils = 0.89; Very disturbed and heavily enriched = 1.00. The values for this attribute were adapted from the New England Institute for Environmental Studies Plant Community Indicator Database (Michner,1990).

The last data analysis step was to process the species, abundance, and attribute data into a set of metrics for each study site. Table 8 displays the Plant Community Index metrics, the rationale for their use, and the predicted response to stressors. Using the reference sites as the bench marks, attributes for each study site were compared and a relative metric score was computed. For each metric, scoring criteria are established by examining the data means, standard deviations, quartiles, and reference values. The plant attributes, index metric scores, and the scoring criteria are contained in Appendix C. The metric scores were then totaled and transformed into a final PCI score.

Table 8. Plant Community Index metrics

METRIC	RATIONALE	RESPONSE TO STRESSORS
Community Similarity	Resemblance of communities to reference site will shift as stressors increase	Decline
Taxa Richness	Total number of plant species will change as stressors increase	Variable
Persistent Standing Litter	Decomposition of vegetation provides important food chain support and habitat structure	Rise
Invasive	Increased presence of invasive species reduces habitat and other wetland functions	Rise
Opportunistic	Opportunistic species will colonize or persist as habitat conditions are altered by stressors	Rise
Flood tolerance (freshwater sites only)	Species with higher flood tolerance will colonize or persist as duration of flooding changes	Variable
Salinity tolerance (salt marsh sites only)	Species with lower salinity tolerance will colonize or persist with change in tidal hydrology	Decline
Nutrient status	Species composition will shift with nutrient enrichment and elevated eutrophication	Decline

Recommendation 6: Revise data analysis protocol for plants

The following revisions to the data analysis protocol documented in Carlisle et al. 1998 for the wetland plants component have been made. These changes are proposed to make the plant multi-metric index more responsive and accurate.

(1) For the Persistent Standing Litter metric, only values for herbaceous plants should be utilized. All shrubs and trees are woody and contain persistent material by nature. The rationale for incorporating the persistent standing litter metric is to determine the extent of the herbaceous community that dies back and releases organic material for consumption, decomposition, and food chain support. In addition, persistent herbaceous species often outcompete other forbs and graminoids that die back. The metric scoring criteria should be adjusted to reflect this change.

(2) Scoring criteria for all the metrics should be examined in light of new data from this and future projects. The best attainable condition as established by the overall reference condition should be adjusted as the reference condition data set expands with each new reference study site for new projects. The metric scoring criteria are determined by this reference condition and the dispersion of plant attribute data from impacted study sites.

(3) The use of the Wetness metric should be abandoned. The Wetness metric is the overall wetland plant indicator status for each site, weighted according to the species' abundance. Higher scores indicate more plants with "wetter" or "obligate" indicator status. It was initially thought that with altered hydrology, the Wetness metric would respond accordingly—more runoff, wetter site, high score. In fact, with further analysis, the wetness metric did not seem to be responding to human disturbance, and therefore should be abandoned until a better relationship can be established.

Results

Freshwater Wetlands

Eighty-seven species were represented throughout the seven freshwater wetland study sites. The most common species were: *Acer rubrum* (6 sites), *Galium tinctorium* (6 sites), *Lythrum salicaria* (6 sites), *Carex lurida* (5 sites), *Impatiens capensis* (5 sites), *Onoclea sensibilis* (5 sites), *Rhamnus frangula* (5 sites), and *Viburnum dentatum* (5 sites). The species with the greatest overall abundance (all sites combined) were, in order of abundance: *Lythrum salicaria*, *Typha angustifolia*, *Cephalanthus occidentalis*, *Acer rubrum*, *Impatiens capensis*, and *Rhamnus frangula*. Of particular note here is the widespread presence and significant abundance of the non-native, invasive *Lythrum salicaria*. The highest number of taxa occurred in sites TAS (34-reference), TCS (28), and IWN (28), and the lowest number occurred in site IWS (15-reference) and DTS (22). The mean taxa for the freshwater sites was 24.9. Table 9 displays the final PCI scores for the freshwater sites.

Salt Marsh Wetlands

Twenty-five species were identified in the seven salt marsh study sites. Six species were found at each of the seven salt marsh study sites: *Distichlis spicata*, *Juncus gerardii*, *Limonium nashii*, *Phragmites australis*, *Spartina alterniflora*, and *Spartina patens*. The species with the greatest overall abundance (all sites combined) were, in order of abundance: *Spartina patens*, *Spartina alterniflora*, *Juncus gerardii*, *Distichlis spicata*, *Phragmites australis*, and *Iva frutescens*. The highest number of taxa occurred in site GGH (20); the average taxa was 13.38; the other six sites had total taxa within 3 of this mean. Table 9 displays the final PCI scores for the salt marsh sites.

Table 9. Plant Community Index scores

Freshwater Sites	**IWS**	**TAS**	**IWN**	**TCS**	**BCH**	**BTC**	**DTS**
PCI score	100	100	62	52	29	76	38
Salt Marsh Sites	**ICB**	**ECR**	**GGH**	**IPB**	**ETC**	**ECP**	**DWR**
PCI score	100	95	52	48	76	76	71

7. Invertebrates

Method

Within the freshwater wetlands, three randomly selected composite (D-Net and Sediment Corer) samples were taken as follows: The D-Net was held fully extended to the right hand side of the body, and starting at the surface of the water, a 180^{o} sweeping arc was prescribed, incrementally descending through the vegetation and the water column downwards to complete the sweep on the left hand side at the sediment interface. The net containing the sample was brought straight up to the surface for retrieval. The retrieved contents of the net were inverted over a bucket, and using a baster, all debris and invertebrates washed free of the net into the bucket. The net was carefully examined for any clinging organisms and vegetation, and removed with forceps to the bucket. The bucket contents were strained through a standard U.S. No. 30 brass sieve to remove water, and placed into a zip-lock bag, ensuring that no invertebrates were left on the sieve. Sediment samples were collected using a Wildco 5.5 cm diameter hand core sediment sampler.

Within the salt marshes, three randomly selected composite (rectangular frame, D-Net, soil auger) samples were taken at the low tide line on the bank and within the water and sediments as follows: a rectangular metal frame, 25 cm x 40 cm, was placed on the surface of the marsh bank, and all visible living organisms found within the frame were identified and counted; the water column and vegetation were sampled using a D-frame aquatic net that was held fully extended to the right hand side of the body at the water surface, and in an arching sweep pulled slowly downwards through the floating and attached marine vegetation and water column to rest at the sediment interface on the left hand side of the body. At that point the net was brought sharply to the surface for the retrieval of the contents. Sediment samples were collected using AMS 3 1/4" diameter sand auger.

Samples were bagged, preserved in 70 percent isopropyl alcohol, labeled, and returned to the laboratory for sorting, identification to family level, and enumeration, without subsampling.

All freshwater and salt marsh wetlands were characterized and sampled during the week May 18 to 22, 1998.

Recommendation 7: Increase number of invertebrate samples in freshwater wetland sites

To ensure more representative sampling, the number of composite D-Net sweeps should be increased to nine per site, with three sweeps taken at each of three stations selected at each wetland site.

Recommendation 8: Sample invertebrates at two times/seasons

Based on literature, other principal investigators' experience with invertebrate sampling, and the pilot Waquoit project, two distinct invertebrate surveys should be conducted. A single sample run in the late spring may not be sufficient to adequately characterize the resident population. The effects of seasonal fluctuations in rainfall and temperature may be amplified with a single sample run, even with replicate samples. There are differences in life cycles within macroinvertebrate orders and families. The aquatic stage does not always occur in the spring, and to accurately represent the community present, at least two seasons per year should be surveyed. The recommended sample periods are late spring/early summer and late summer/early fall.

Recommendation 9: Improve invertebrate sampling methods

So that a more representative sample of the salt marsh community is obtained, suggested improvements to salt marsh sampling strategies include:

- The addition of sweep net sampling of the marsh grass in the high tide zone when this zone is flooded; and
- The addition of a sampling plot on the substrate of the salt marsh during low tide, using a rectangular frame.

Data Analysis

A multi-metric approach, using the reference condition as the basis of comparison, was used to analyze the raw data, compile individual metric scores, and derive a final Invertebrate Community Index (ICI). Throughout this study, the freshwater and the salt marsh sites were evaluated and compared separately. Data obtained from each study site were entered into computer spreadsheet files (Excel 97), compiled, and metrics were generated as described below. Statistical analysis was completed primarily by computer software (Excel 97). Next, the taxa, abundance, and attribute data were processed into a set of metrics for each study site. The metrics and indices utilized are listed in Tables 10 (freshwater) and Table 11 (salt marsh) with the rationale for their use and the predicted response to stressors. Using the reference sites as the bench marks, invertebrate attributes for each study site were compared and a relative metric score was computed. For each metric, scoring criteria are established by examining the data means, standard deviations, quartiles, and reference values. The ICI index and metric scores and the scoring criteria are contained in Appendix D. The metric scores were then totaled and transformed into a final ICI score.

Table 10. Freshwater invertebrate community metrics and indices

METRIC/INDEX	**RATIONALE**	**RESPONSE TO STRESSORS**
Total Number of Organisms	Nutrient enrichment will usually support higher numbers of organisms. Toxicity and habitat degradation will reduce numbers.	Variable
% Contribution of Major Feeding Groups	A healthy community will have a balance between the various trophic groups.	Variable
% Contribution of Dominant Family	A healthy community will have a balanced composition between taxa, with more than 2 dominant groups.	Rise
Taxa Richness	Diversity is a measure of community complexity that responds adversely to stress intensity.	Decline
EOT Richness (*Ephemeroptera, Odonata, Trichoptera*)	Healthy systems have greater numbers of sensitive taxa and predator-guild organisms.	Decline
EOT/*Chironomidae* Ratio	Healthy systems have higher sensitive taxa to tolerant taxa ratios.	Decline
Other *Odonata/Coenagrionidae* Ratio	Healthy systems have higher sensitive to tolerant Odonate ratios.	Decline
% Tolerant / % Intolerant Ratio	Impacted systems have higher tolerant to intolerant organism ratios.	Rise
Family Biotic Index	Community's averaged tolerance value will rise with increasing stressors.	Rise
Community Taxa Similarity Index	Resemblance of taxa composition to reference will shift with stressors.	Decline
Community Trophic Similarity Index	Resemblance of trophic pattern to reference will shift with stressors.	Decline
Invertebrate Community Index	Overall community condition will decline with increasing degradation.	Decline

Table 11. Salt marsh invertebrate community metrics and indices

METRIC/INDEX	RATIONALE	RESPONSE TO STRESSOR
Total Number of Organisms	Nutrient enrichment will usually support higher numbers of organisms. Toxicity and habitat degradation will reduce numbers.	Variable
% Contribution of Dominant Taxonomic Group	A healthy community will have a balance between the various trophic groups.	Rise
% Contribution of Dominant Trophic Group	A healthy community will have a balanced composition between taxa, with more than 2 dominant groups.	Rise
Taxa Richness	Diversity is a measure of community complexity that responds adversely to stress intensity.	Decline
% Abundant / % Rare	Ratio of common to rare families will increase with stressors.	Rise
% Capitellid polychaete worms	Numbers of organism rise with stressors; indicator of eutrophication.	Rise
% Palaemondedae shrimp	Numbers of organism rise with stressors; indicator of eutrophication.	Rise
Community Taxa Similarity Index	Resemblance of taxa composition to reference will shift with stressors.	Decline
Community Trophic Similarity Index	Resemblance of trophic pattern to reference will shift with stressors.	Decline
Invertebrate Community Index	Overall community condition will decline with increasing degradation.	Decline

Recommendation 10: Add to and revise freshwater wetland invertebrate metrics

In order to identify metrics that respond to disturbance, future testing of the transferability of the invertebrate protocol should consider the addition and alteration of the following metrics:

- Inclusion of a Community Loss Index (predicted taxa not present).
- Inclusion of a % Predators metric (number of predator taxa).
- Testing the following families as suitable for positive response to impairment metrics:
  - Oligochaeta: Lumbriculidae, Gastropoda: Lymnaeidae
  - Amphipods: Crangonyctidae, Gammaridae
  - Isopods: Asellidae
- Testing the following families as suitable negative dose response to impairment
  - Gastropoda: Physidae and Sphaeriidae
  - Collembola: Poduridae
- Split ratio metrics such as % Tolerant/% Intolerant Ratio, and % Other Odonata/ % Coenagrionidae Ratio to simple metrics % Tolerant, % Other Odonata, % Intolerant, and % Coenagrionidae.

Recommendation 11: Add to and revise salt marsh invertebrate metrics

In order to identify metrics that respond to disturbance, future testing and improvement of the degree of transferability of the invertebrate protocol should consider the addition and alteration of the following metrics :

- Inclusion of a Community Loss Index (predicted taxa not present).
- Inclusion of a % Predators metric (number of predator taxa).

Other possible attributes to consider as metrics:

- Richness of *Polychaete* worms taxa.
- Richness of *Amphipoda* taxa.
- Richness of Shrimp taxa.
- % Invasive introduced species such as *Carcinus maenus, Hemigrapsus sanguineus, Littorina littorea.*

Results

Freshwater Wetlands

Thirty-five families were represented throughout the seven freshwater wetlands sampled. The most commonly occurring families were *Asellidae, Chironomidae, Lumbriculidae, Sphaeriidae, Crangonyctidae, Dytiscidae* and *Limnephiloidae*. Those that occurred rarely throughout the freshwater wetlands were *Lumbricidae, Enchytraeidae, Sminthuridae, Leptophlebiidae, Libellulidae, Mesoveliidae, Curculionidae, Elimidae, Stratiomyidae,* and *Turbellaria*. Overall abundance of organisms was highest in wetland sites BCH (120) and TAS (76), and lowest in wetland sites IWN (19) and IWS (30), and the average abundance for all sites was 53.3. The highest number of taxa occurred in wetland sites BCH (17) and IWN (15) and the lowest in wetland site IWS (4). Average taxa richness for all sites was 12.3. Table 12 gives the index scores for the freshwater wetlands.

Salt Marsh Wetlands

Thirty-eight families/groups were represented throughout the seven salt marsh wetland sites sampled. The most commonly occurring families were *Capetellidae, Nereidae, Spionidae, Gammaridae,* and *Mytilidae*. There were eighteen families that were found only once throughout all seven salt marsh sites. Overall abundance of organisms was highest in salt marsh sites ECP (47), ECR (36), ETC (32), and ICB (31), and lowest in salt marsh IPB (2). The average abundance for all sites was 27.8. Table 12 gives the index scores for the salt marsh wetland sites.

Table 12. Invertebrate Community Index scores

Freshwater Sites	**IWS**	**TAS**	**IWN**	**TCS**	**BCH**	**BTC**	**DTS**
ICI score	100	100	59	72	62	56	54
Salt Marsh Sites	**ICB**	**ECR**	**GGH**	**IPB**	**ETC**	**ECP**	**DWR**
ICI score	100	100	70	74	85	74	67

8. Water Chemistry

Method

Water chemistry measurements were made at a single station at each wetland study site on a seasonal basis from Winter 1997 to Summer 1998. Constituents that were sampled in this investigation include:

- Temperature (degrees C)
- pH
- Conductivity (uS)
- Salinity (ppt)
- Dissolved oxygen (mg/l)
- Total suspended solids (mg/l)
- Nitrate plus nitrite (mg/l)
- Ammonia (mg/l)
- Ortho-phosphate (mg/l)
- Total fecal coliform bacteria (number/100 ml)

All samples were collected with standard techniques as outlined in *Handbook for Sampling and Sample Preservation of Water and Wastewater* (EPA-600/4-82-029). All water chemistry sampling was completed in accordance with an approved Quality Assurance Project Plan (QAPP).

Measurements for temperature, conductivity, pH, and dissolved oxygen were obtained in the field with the use of a YSI 600 probe and data logger. Within one hour of beginning a sampling run, the YSI probe was calibrated in the laboratory using methods described in the *YSI 600 Multi-Parameter Water Quality Monitor Instruction Manual*.

For all other parameters, sample bottles were all acid-washed or pre-sterilized, with the exception of the 250 ml fecal coliform bottles, which were autoclaved. Samples were collected by trained Project Team personnel. Sample identification information was completed at the time of sampling. Sample IDs included name, site, date, time, and assay. All samples were maintained on ice and in dark from collection in the field through transport directly to the laboratory where the chemical analyses were performed. Sampling was coordinated so that samples were analyzed within QAPP-specified holding times.

Field data sheets were maintained by Project Team personnel to document each sampling event. The field data sheets record location, station, date, time of each sample, number of samples by constituent, number of QA samples, weather conditions, physical conditions, and other relevant information.

Samples were collected from pre-selected stations (selected based on representation of a particular wetland type and to encompass the range of environmental variability found within the system).

Laboratory analyses methods and holding times are shown in Table 13.

Table 13. Methods, reference, and holding times

PARAMETER	HOLDING TIME	METHOD	REFERENCE
Nitrate/Nitrite	48 hours	300.0 4500-NO2 seawater	EPA SM 18th ed.
Ammonium	28 days	350.2	EPA
Dissolved Kjeldahl N	28 days	351.3	EPA
Ortho-phosphate	48 hours	300.0 365.2 seawater	EPA EPA
Total Suspended Solids	7 days	2540D	SM 18th ed.
Fecal Coliforms	6-24 hours	9221E	SM 18th ed.

EPA: Methods for Chemical Analysis of Water and Wastes, USEPA.
SM: Standard Methods for the Examination of Water and Wastewater.

Freshwater sites were sampled on three occasions: December 1997, March 1998, and June 1998. The salt marsh sites were sample in: January 1998, March 1998, and July 1998.

Data Analysis

In the attempt to utilize the Waquoit pilot project multi-metric approach to analyze the water chemistry data from this North Shore Transfer Project, it became clear that there were some difficulties in this transfer. The biggest problem stemmed from the fact that the North Shore water chemistry data had generally much higher values as well as wider ranges. Another problem was that the North Shore project laboratory's capabilities and techniques did not allow for low enough detection limits for several nutrient parameters, especially for ortho-phosphorous. In all cases, for all samples, the reported values were below detection limits. These detection limits were an order of magnitude higher than the laboratory was able to achieve for the Waquoit project.

Because the North Shore wetland water chemistry data did not readily fit into the model and protocol developed for the Waquoit pilot project, the use of a multi-metric type of analysis for water chemistry should be reconsidered. Because wetlands have such high natural variability both within a site and between sites, the water chemistry data might be most appropriately utilized as supporting information to further assist in the interpretation of biological results (see Recommendation 13). The metrics and indices utilized are listed in Table 14 with the rationale for their use and the predicted response to stressors. The Water Chemistry Index (WCI) and metric scores and the scoring criteria are contained in Appendix E. The metric scores were then totaled and transformed into a final WCI score.

Table 14. Metrics for Water Chemistry Index

METRIC	RATIONALE	RESPONSE TO STRESSORS	METRIC COMPUTATION
Specific Conductivity (Freshwater sites only)	Conductivity levels indicate presence of dissolved inorganic compounds	Rise	Absolute difference from reference value
Salinity (Salt marsh sites only)	Salt marsh biological communities are dependent on specific saline levels	Decline	Mean PPT for study site
Fecal Coliform Bacteria	Fecal coliform bacteria is harmful to human health	Rise	Mean CFU for study site
Ortho-Phosphates	Accelerate primary productivity, eutrophication, algal blooms, invasive plant species	Rise	Mean concentration (mg/l) for study site
Ammonia	Accelerate primary productivity, eutrophication, algal blooms, invasive plant species	Rise	Mean concentration (mg/l) for study site
Nitrate/Nitrite	Potentially harmful to human health; accelerate primary productivity, eutrophication, algal blooms, invasive plant species	Rise	Mean concentration (mg/l) for study site

Results

Table 15 displays the WCI scores for the freshwater wetland and salt marsh study sites. These scores were computed without the total suspended solid metric, as data coverage was insufficient. In addition, as ortho-phosphorous concentrations for each freshwater wetland sample were below the detection limit, all freshwater sites scored identically for phosphorous metric.

The freshwater wetland sites' WCI scores ranged from a high of 94 (IWS) and a low of 47 (BCH, DTS, BTC), and the mean freshwater WCI score was 60, with a standard deviation of 17.

The salt marsh WCI scores ranged from a high of 87 (ETC) to a low of 60 (ECP, GGH). The mean WCI for salt marsh sites was 71, and the standard deviation was 11.

Table 15. Water Chemistry Index scores

Freshwater Sites	**IWS**	**TAS**	**IWN**	**TCS**	**BCH**	**BTC**	**DTS**
WCI score	93	60	60	67	47	47	47
Salt Marsh Sites	**ICB**	**ECR**	**GGH**	**IPB**	**ETC**	**ECP**	**DWR**
WCI score	80	67	60	67	87	60	80

Recommendation 12: Use methods capable of low detection limits for nutrient parameters

Through this application of the wetland water chemistry sampling and analysis protocols, it became evident that in many wetland systems, nutrient levels, though present, may be in low concentrations. This is likely due to the active uptake of bio-available nutrient forms by macrophytes and algae. The recommendation here is, where possible, to utilize laboratory equipment and methods that permit detection of low concentrations. Detection limits for nitrogen and phosphorous forms should be lower than 0.05 mg/l.

Recommendation 13: Eliminate the use of multi-metric approach for wetland water chemistry

The application of a multi-metric protocol to wetland water chemistry data may not be a suitable or valid application of this data analysis technique. The application of this approach for wetland water chemistry data for both freshwater and salt marsh sites on the North Shore revealed several limitations and problem areas. Because wetland systems are comparatively dynamic, and wetlands interact strongly with both biotic and abiotic components, chemical parameters in wetlands are highly variable. In addition, while candidate wetland study sites may be very similar in classification by type, dominant vegetation, and general hydrology, other factors such as geomorphology (specific position in the landscape) and site-specific hydrology may exert significant influence on water chemistry. The use of a multi-metric data analysis approach does not appear to be a good fit for examining water quality sampling results. The water chemistry data is more suitably utilized as supporting information to further assist in the interpretation of biological results.

9. Stormwater Discharges to Wetlands

Background

Wetlands provide a multitude of functions in the natural landscape, such as serving as critical wildlife habitat, managing flood waters, and improving water quality. The ability of wetlands to improve water quality has been well documented (Mitsch and Gosselink, 1993; Meiorin, 1989; Whigham et al., 1988; Hemmond and Benoit, 1988). Due to their natural landscape positions and depositional characteristics, wetlands commonly receive anthropogenic sources of pollution. Unique biogeochemical conditions in wetlands create strongly reducing environments (low or no oxygen, anaerobic) that allow wetlands to assimilate or transform a wide array of pollutants, including nutrients, sediments, metals, and biological and chemical oxygen demanding substances. Unfortunately, urban stormwater and agricultural runoff, sewage disposal practices, sedimentation from construction and forestry activities, and other sources of pollutants have the potential to overload a wetland's capacity for assimilation and significantly alter wetland biological communities and the subsequent food chains they support, reduce flood storage capacity, and impair drinking water supplies.

The continuous increase of nutrient and bacteria inputs, primarily the result of increased point and nonpoint source (NPS) inputs via increasing coastal development, are of growing concern to coastal communities. The apparent decline of coastal water quality over recent decades is generally attributed to the increased loads from these sources. Point source nutrient and bacteria inputs tend to be discrete and readily quantifiable, while NPS pollution is more diverse and difficult to identify and measure. The primary causes of NPS pollution are residential waste disposal, fertilizer use (agricultural and residential), dairy and cattle farming, direct precipitation and stormwater runoff. The last, stormwater runoff, is of particular concern in urban, suburban and urbanizing areas. With increased development comes increased paving of surfaces and subsequent increases of nutrient and pollutant loading via this pathway.

The understanding of nutrient inputs to coastal waters via stormwater runoff, however, is limited and little quantitative data exists to evaluate various management options to remediate or limit inputs from this source. This lack of information is unfortunate since proper management requires quantitative data to make informed decisions as to options for watershed development and remediation.

Due to its apparent role as a major source of disturbance to wetland ecological integrity in the Waquoit pilot project, stormwater inputs to wetlands needed further characterization. A fundamental component of this North Shore transfer project was the independent investigation of direct stormwater discharges to wetlands. In late 1998 and into early 1999, CZM issued request for responses, received bids, and selected a vendor to provide the stormwater sampling, analysis, and assessment components of the project. In April 1999, the Louis Berger Group signed the contract and began work on the investigation.

The Berger Group sampled three storm events at each of two selected wetland study sites. For each discrete sample, analysis was provided for the following constituents:

- Nitrite/Nitrate nitrogen
- Ammonia nitrogen
- Dissolved organic nitrogen
- Particulate organic nitrogen/carbon
- Ortho-phosphorous
- Total suspended solids
- Fecal coliform
- Total Petroleum Hydrocarbons (abandoned after 2 storms, below detection limit)

In addition, for each discrete sample, the following parameters were measured in the field.

- Dissolved oxygen
- Conductivity
- pH
- Temperature

Measurements of flow and appropriate physical parameters were conducted in the field with parallel samples of stormwater collected for laboratory chemical analysis.

All work was completed under the protocols and methods of a Quality Assurance project Plan, approved by the US Environmental Protection Agency.

The information generated from this work allowed for the characterization of types, concentrations, and loading rates of pollutants entering wetlands from stormwater runoff from two general classes of land use: residential and commercial/industrial. A final report was developed by the Berger Group, summarizing the sampling protocols, describing the results of each sampling event, and explaining the methodology, process, and results of the loading analysis. The report can be accessed from: http://www.state.ma.us/czm/wetlandnorthcoastalstormwatersampling.pdf

Site Selection

Of the 14 wetland study sites for the Wetland Ecological Assessment Project, eight sites have direct and unmitigated stormwater discharges. The evaluation of stormwater discharges from differing land-uses was an important aspect of the project. Due to the cost and complexity of stormwater sampling, lab analysis, and assessment, CZM decided to select two sites for stormwater assessment work. The objective of selecting two sites was to try to identify sites with drainage basins containing different land use types and characteristics.

The two wetland sites selected for assessment were the Ipswich Willowdale North (IWN) at Pinefield Street and the Beverly Cherry Hill site (BCH) on the Danvers/Beverly town line. The contributing land use of site IWN is characterized by medium density residential development, while the contributing land use at the BCH site is characterized by industrial/commercial (office park and interior processing/shipping). Both sites had defined contributing areas and discharge points which allowed sampling of flow and constituent load. These physical features helped to constrain the stormwater loading estimates derived from the field program.

Site Descriptions

As previously stated, two sites were selected for this study:

- ✓ IWN site: Runoff from residential neighborhood.
- ✓ BCH site: Runoff from parking lot and industrial buildings.

Wetland Study Site: IWN

This site is located in Ipswich at the southern end of the Pinefield development and in the northern part of the Willowdale State Forest (Figure 17). The development consists entirely of single family homes. The stormwater sampling location was located at the southern end of two parallel pipes (diameter 12") underneath Linebrook Road. Stormwater that exits the pipe flows within a partially vegetated drainage channel into the wetland. The drainage channel is roughly 15 m long. The approximate drainage area for the sampling location was estimated during a site visit during a rainstorm in April 2002. The size of the area is 76,922 m^2. The estimated total impermeable surface area is 19,775 m^2 (or 26% of the total drainage area).

Figure 17. Site IWN, showing drainage area and discharge

Wetland Study Site: BCH

The site is located in Beverly and Danvers just to the south of the Beverly Municipal Airport within the Cherry Hill Industrial Development area (Figure 18). The wetland receives runoff from the parking lot of the development at mainly three discharge locations. In addition, the wetland receives runoff from adjacent industrial developments. The sampling location was one of the three stormwater pipes that drain the parking lot from the 35 Cherry Hill Drive development. The selected pipe was located at the eastern end of the parking lot. The stormwater enters two manholes just above the wetland. The water is first contained in a catch basin. The overflow of the catch basin is discharged through a 12" diameter pipe into the wetland. The approximate drainage area was also determined during a site visit during a rainstorm in April 2002. The estimated drainage area for the sampling location was 5,490 m^2. The estimated total impermeable surface area was 5,290 m^2 (or 96% of the total drainage area).

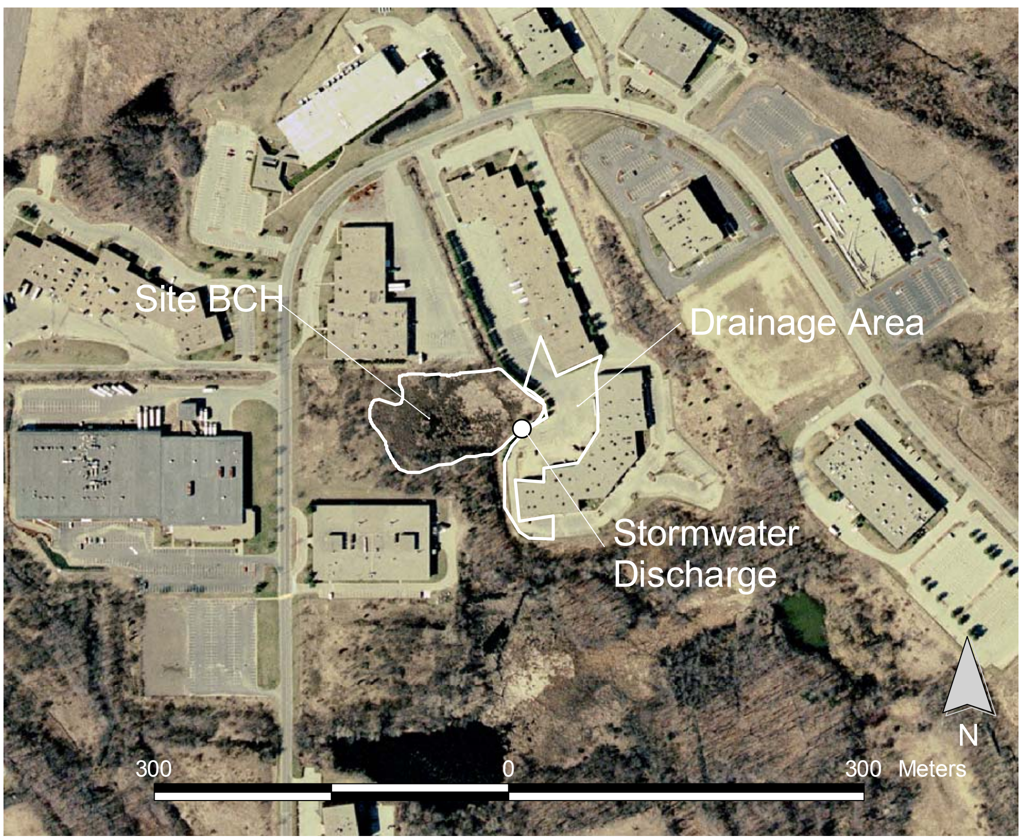

Figure 18. Site BCH, showing drainage area and discharge

Method

Sampling was conducted during three storms at each site. The samples were subsequently transported to the UMass Coastal Systems Laboratory at SMAST for nutrient and TSS analyses. Samples for fecal coliform analyses were delivered to Toxikon (Storms A to D), and to the Barnstable County Laboratory (Storms E and F).

Storms to be sampled required the following criteria:

- ✓ Dry period prior to the storm: at least 36 hours.
- ✓ Rainfall amount: 0.33" of rain per storm.

Stormwater sampling was conducted on the dates and at the sites in Table 16.

Table 16. Stormwater sampling dates and sites

Storm	Site	Rainfall Amount
Storm A: August 23, 2000	BCH	0.32"
Storm B: September 15, 2000	IWN	1.23"
Storm C: November 10, 2000	BCH	1.12"
Storm D: September 21, 2001	IWN	0.30"
Storm E: September 25, 2001	IWN	0.60"
Storm F: April 25, 2002	BCH	0.93"

The sampling staff arrived at least one hour before the beginning of the storm. Basic information was recorded in the field notebook. The dissolved oxygen (DO) and pH meter calibrations were checked. The site was prepared for flow measurements.

The goal of the sampling effort was to capture the load of constituents that enter the wetland at the two study locations for a specific storm. To meet this goal, samples were collected during the first flush with more frequent sampling at the beginning of the storm. Sampling intervals become longer toward the end of the storm. The last sample was reserved for the end of the flow period. Given that all storms are different, flexibility was maintained by setting the sampling interval to assure that the sampling goal was met.

A total of 10 samples from each site per sampling event were analyzed. This number of samples included one duplicate sample. Prior to collecting each sample, the sample labels were filled out completely. Samples were placed into a cooler on ice immediately after sampling. Conductivity, dissolved oxygen, pH, and temperature were measured in the field with automated meters. The meters were calibrated before and after each sampling events. Flow measurements were made at each site immediately after the collection of each water sample. In addition, the flow was measured between water samples.

At each location, at least one rain gauge was deployed. The gauge consisted of graduated cylinder with an accuracy of 0.01" of rain. The gauge was deployed prior to the start of rainfall at an appropriate unobstructed location near the sampling location. Rain gauge readings were taken with each flow measurement. Additional readings were taken between water samples in order to understand the dynamics of the storm.

Rainfall information was also recorded by the Beverly Municipal Airport. The airport is located approximately 8 miles from the Pinefield site and approximately 0.5 miles from the Cherry Hill site. The readings are published on the NOAA National Weather Service website. Rainfall data were compared also to measurements collected by the following sources:

- IWN site: Rainfall information is collected daily at 7:00am at the Ipswich Wastewater Treatment Plant. The rain gauge used in Ipswich is a graduated cylinder model with an accuracy of 0.01". The treatment plant is approximately 3.3 miles east of the IWN study site.
- BCH site: Rainfall information is collected daily at 8:00am at the laboratory of the Beverly Salem Water Supply Board. Data are collected with a standard USGS rain gauge which is a graduated cylinder model with an accuracy of 0.01". The laboratory is located just to the south of Wenham Lake, approximately 1.3 miles ENE of the BCH study site.

Storm water studies indicate that concentrations of contaminants can range over several orders of magnitude both within a single event (first flush versus final levels) and between events, depending on the volume and frequency of rainfall. As a result, methods with low detection levels were selected to ensure quantitative results. The methods employed in the nutrient assays were the standard methods of research level environmental laboratories.

Monitoring parameters, sample volumes, containers, sample processing and storage for this investigation are listed in Table 17. Analyses were conducted within the recommended holding times specified in Table 18. Analytical methods and associated references are listed in Table 19.

Table 17. Monitoring parameters, volumes, containers, processing and storage

Parameter	Volume	Container*	Processing and Storage
Nitrate + Nitrite	60 ml	Polyethylene (HCl leached)	0.45um membrane; field filtration; stored on ice (dark)
Dissolved Ammonium	60 ml	Polyethylene (HCl leached)	0.45um membrane; field filtration; stored on ice (dark)
Total Dissolved Nitrogen	60 ml	Polyethylene (HCl leached)	0.45um membrane; field filtration; stored on ice (dark)
Particulate Carbon Nitrogen	1000 ml	Polyethylene or solids	Acid washed; combusted GFF; dried; stored on ice (dark)
Ortho-Phosphate	60 ml	Polyethylene (HCl leached)	0.45um membrane; field filtration; stored on ice (dark)
Total Phosphorous	1000 ml	Polyethylene (HCl leached)	stored on ice (dark)
Total Suspended Solids	1000 ml	Polyethylene	stored on ice (dark)
Specific Conductance	60-125 ml	Polyethylene	no headspace in bottle; stored on ice (dark)
Fecal Coliform	100 ml	Polyethylene (sterilized)	stored on ice (dark)
Total Petroleum Hydrocarbons	1000 ml	Amber/glass bottle (bottles are acidified with HCl to pH < 2)	stored on ice (dark)

(*) The acid used for acid-washed bottles was 10% hydrochloric acid.

Table 18. Assays, holding times, laboratories

Assay	Holding Time	Lab
Nitrate + Nitrite	48 hours	SMAST
Dissolved Ammonium	12-24 hours	SMAST
Total Dissolved Nitrogen	12-24 hours	SMAST
Particulate Carbon Nitrogen	24 hours	SMAST
Ortho-Phosphate	12-24 hours	SMAST
Total Phosphorous	24 hours	SMAST
Total Suspended Solids	24 hours	SMAST
Fecal Coliform	24 hours	Toxicon/BCL
Total Petroleum Hydrocarbons	28 days	Toxicon

Table 19. Analytical methods and associated references

Parameter	Matrix	Units	Method	Reference
Nitrate + Nitrite	Water	ug/L	Autoanalyzer	A
Dissolved Ammonium	water	ug/L	Indophenol	B
Total Dissolved Nitrogen	water	ug/L	Persulfate digest	C
Particulate Carbon Nitrogen	water	ug/L	Elemental analysis	D
Ortho-Phosphate	water	ug/L	Molybdendum blue	E
Total Phosphorous	water	ug/L	Persulfate digest molybdendum blue	F
Total Suspended Solids	water	mg/L	Filtration/drying	G
Specific Conductance	water	Ms/m	Meter and probe	H
Fecal Coliform	water	CFU/mL	Membrane filtration	I
Total Petroleum Hydrocarbons	water	mg/L	IR	J

A Lachat Autoanalysis procedures based upon the following techniques
- Wood, E., F. Armstrong and F. Richards. 1967. Determination of nitrate in sea water by cadmium copper reduction to nitrite. J. Mar. Biol. Ass. U.K. 47:23-31.
- Bendschneider, K. and R. Robinson. 1952. A new spectrophotometric method for the determination of nitrite in sea water. J. Mar. Res. 11: 87-96.

B Scheiner, D. 1976. Determination of ammonia and Kjeldahl nitrogen by indophenol method. Water Resources 10: 31-36.

C D'Elia, C.F., P.A. Stuedler and N. Corwin. 1977. Determination of total nitrogen in aqueous samples using persulfate digestion. Limnol. Oceanogr. 22: 760-764.

D Perkin-Elmer Model 2400 CHN Elemental Analyzer Technical Manual.

E Murphy, J. and J. Riley. 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica Chimica Acta 27: 31-36.

F Persulfate Digestion Method for Total Phosphorus; Standard Methods 4500-P B.5 (18th ed.).

G Total Suspended Solids dried at 103-105^{o}C, Standard Methods 2540 D (18th ed.).

H Conductivity, Standard Methods 2510 B. (18th ed.), Fisher Temp. Compensated Conductivity Meter.

I Fecal coliform, Standard Methods 9221 E. (18th ed.).

J TPH, Standard Methods 418.1.

Data Analysis

The instantaneous mass flux (discharge * concentration) of the reported analytical data for composite samples was calculated by integrating the flux of a specific constituent in relation to its discharge to determine the pollutant load.

Discharge volumes were calculated from the flow rates. Flow rates were verified by the rainfall volume (rainfall rate times drainage area). The instantaneous mass discharge was calculated by multiplying the concentration data by the flow rate at each sampling time. The mass load for the entire storm was then estimated by integrating under the Mass x Time curve developed for each constituent from the sampling time-course over the entire storm period.

Average annual discharge rates per square meter were calculated for each site for both the total and the impervious areas.

Results: Rainfall and Flow

The average annual rainfall rate measured by the Salem Beverly Water Supply Board from the years 1950 to 2002 was 43.2 inches (Figure 19). The annual rainfall rate increased slightly over the 52 year long period. The average monthly variability was very low, ranging between 3.1 inches in June to 4.4 inches in November. Storms exceeding 0.3 inches contributed 85% of the total annual rainfall.

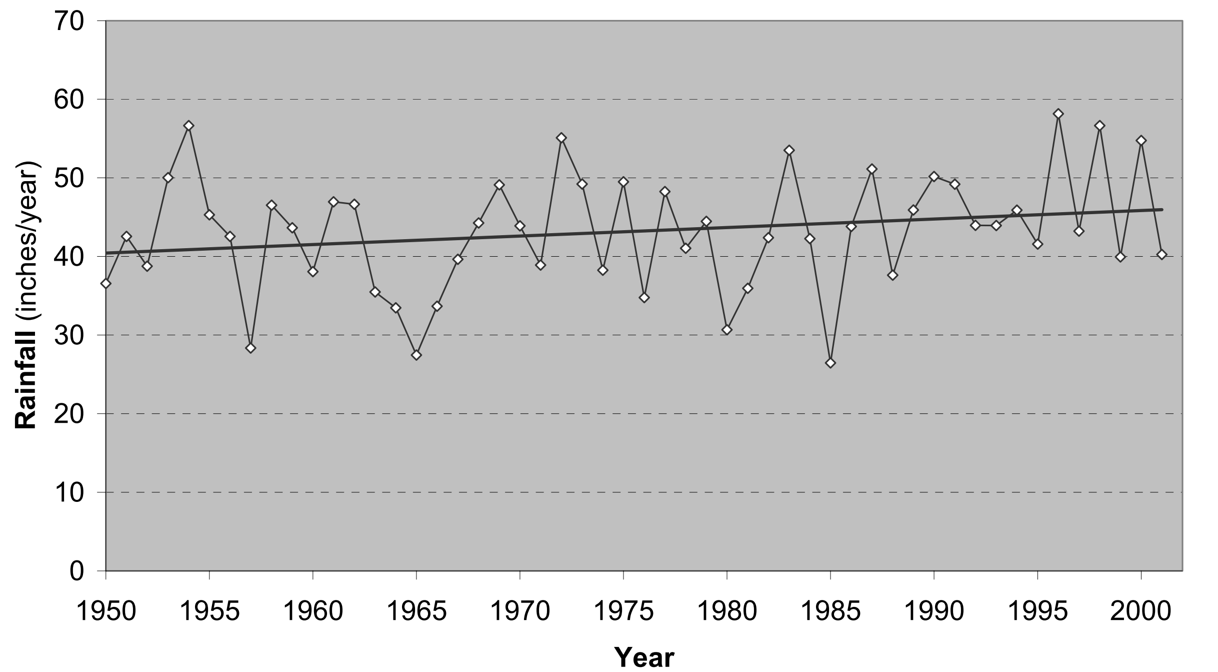

Figure 19. Annual rainfall at Beverly, 1950-2002

Storm A, BCH

The rainfall rate was 0.32 inches. Therefore, the total volume that fell on the drainage area was 45 m^3; the volume that fell on the impervious area was 43 m^3. The total discharge volume measured with the flow meter at the drainage pipe was 37 m^3 (or 82% and 86% of the volume that fell on the total and impervious drainage areas, respectively). The peak flow measured was 0.3 cubic feet per second (cfs). Over 90% of the rainfall fell slowly but steadily over a period of 4 hours. Storm A exhibited a rainfall rate in the 37th percentile; i.e., 37% of the storms exceed the rate of Storm A.

Storm B, IWN

The rainfall rate was 1.23 inches. Therefore, the total volume that fell on the drainage area was 2,403 m^3; the volume that fell on the impervious area was 618 m^3. The total discharge volume measured with the flow meter at the drainage pipe was 497 m^3 (or 21% and 80% of the volume that fell on the total and impervious drainage areas, respectively). The peak flow measured was 2.3 cfs. Over 90% of the rainfall fell steadily over a period of 4 hours. Storm B exhibited a rainfall rate in the 8th percentile; i.e., 8% of the storms exceed the rate of Storm B.

Storm C, BCH
The rainfall rate was 1.12 inches during the period of discharge monitoring. Therefore, the total volume that fell on the drainage area was 156 m^3; the volume that fell on the impervious area was 150 m^3. The total discharge volume measured with the flow meter at the drainage pipe was 152 m^3 (or 97% and 101% of the volume that fell on the total and impervious drainage areas, respectively). In other words, approximately the entire rain volume that fell on the drainage area was discharged at the pipe. The peak flow measured was 0.9 cfs. Over 90% of the rainfall fell with varying intensity over a period of approximately 10 hours. Storm C exhibited a rainfall rate in the 10th percentile; i.e., 10% of the storms exceed the rate of Storm C.

Storm D, IWN
The rainfall rate was 0.30 inches. Therefore, the total volume that fell on the drainage area was 586 m^3; the volume that fell on the impervious area was 151 m^3. However, the total discharge volume measured was only 13 m^3 (or 9% of the volume that fell on the impervious drainage area). The peak flow measured was only 0.07 cfs. Rain fell slowly for a period of approximately 10 hours. Discharge at the pipe did not start until 0.12 inches of light rain had fallen over a period of approximately 6 hours (or 40% of the total rain volume for the storm). Reasons for the discrepancies between measured flow and rain volume include the following:

- *Evaporation of impervious surface:* Due to the slow rainfall rate, some of the rainfall likely evaporated from the impervious surface. The average air temperature on this day was 65F.
- *Infiltration:* Due to the slow rainfall rate, some of the rainfall likely infiltrated into the ground through pervious area as well as other conduits. The storm drain pipes may have some cracks that allow flow to escape into the ground. The percentage of flow disappearing into the ground would be greater during low flow conditions (as existed during this storm).
- *Catch basins:* The drainage system contains a number of catch basins. Rain had not fallen for a period of 5 days. Some of the initial rainfall volume could have been captured by these basins.
- *Rainfall variability:* Two rain gauges were deployed for this storm, approximately 200 m apart. Readings were 0.28 and 0.32 inches suggesting local variability (we used an average of 0.30 inches for our calculations). The Beverly Salem Water Board gage recorded 0.27 inches; the Beverly Municipal Airport gage recorded 0.35 inches. The variability, however, does not account for the discrepancy between the rain volume and measured flow volume.
- *Measurement error*: Flow measurements were all conducted with the graduated bucket, given the low flow conditions. This method is considered very accurate. The variability in flow between measurements was also small. Therefore, a measurement error that would explain the discrepancy is considered unlikely.

Storm D exhibited a rainfall rate in the 40th percentile; i.e., 40% of the storms exceed the rate of Storm D.

Storm E, IWN

The rainfall rate was 0.60 inches. Therefore, the total volume that fell on the drainage area was 1,172 m^3; the volume that fell on the impervious area was 301 m^3. The total discharge volume measured with the flow meter at the drainage pipe was 337 m^3 (or 29% and 112% of the volume that fell on the total and impervious drainage areas, respectively). The peak flow measured was 3.2 cfs. Over 90% of the rainfall fell steadily over a short period of 2 hours. The shorter rainfall period and higher flow rate explains why a greater percentage of the rainfall volume that fell on the drainage area was discharged. Storm E exhibited a rainfall rate in the 22th percentile; i.e., 22% of the storms exceed the rate of Storm E.

Storm F, BCH

The rainfall rate was 0.93 inches. Therefore, the total volume that fell on the drainage area was 130 m^3; the volume that fell on the impervious area was 125 m^3. The total discharge volume measured with the flow meter at the drainage pipe was 326 m^3 (or 261% of the volume that fell on the impervious drainage area). Potential reasons for the discrepancy are as follows:

- *Drainage area:* The drainage area is part of a significantly larger parking lot, drained by several manholes. There are two manholes up-gradient of the drainage area that was studied. There is a possibility that during high flows, rainwater bypasses these up-gradient manholes and flows into the studied drainage area. This scenario was deemed unlikely, as Storm C had an even higher rainfall, 1.12 inches , and showed good agreement between the discharge estimated from the rainfall and drainage area versus the discharge measured at the outlet pipe. Rainwater would bypass, however, if the manholes were blocked by debris.
- *Measurement error:* The flow meter may have provided inaccurate measurements.

Since the stormwater discharge cannot exceed the rainfall volume, the discharge volume was adjusted in our load calculations to a flow rate of 125 m^3 (i.e., the rainfall volume that fell on the impervious surface of the studied area). The peak flow measured was 0.9 cfs. Over 90% of the rainfall fell fairly steadily over a period of 8 hours. Storm F exhibited a rainfall rate in the 13th percentile; i.e., 13% of the storms exceed the rate of Storm F.

The total rainfall volume measured during the three storms at study site IWN was 2.13 inches. This rate corresponds to 4.6% of the average annual rate of 46.5 inches that fell between 1987 and 2001 and 4.9% of the rate of 43.2 inches between 1950 and 2002.

The total rainfall volume measured during the three storms at the BCH study site was 2.37 inches. This rate corresponds to 5.1% of the average annual rate of 46.5 inches that fell between 1987 and 2001 and 5.6% of the rate of 43.2 inches between 1950 and 2002.

Results: Fecal Coliform

IWN

The fecal coliform (FC) concentrations were very high throughout the three storms, reaching 29,000 colonies per 100 ml (co/100ml) during Storm C. There was a clear pulse of fecal coliform in the initial phases of each storm; however, there was no distinct spike in concentrations during the first flush. The most likely reason for the broad initial concentration peak is the long drainage system with several man-holes and catch basins. This situation results in longer travel times for the more distant input points and a mixing of this water with "cleaner" water from the already flushed lower part of the system. The contribution of septic systems from the residential area is not known. However, the results do not necessarily indicate septic system inputs, as surface water inflow from runoff sources would also produce the observed pattern. Functioning septic systems are an unlikely source of coliforms, since transport of fecal coliforms in soil is very low. The primary mechanism for septic system fecal coliforms to enter the stormwater system is via direct hook-ups or effluent "breakout." If direct discharges of septic wastewater to the stormwater system were occurring, there would be large changes in concentration from dilution, but the load per unit time would be relatively constant. Instead, the concentration and the load of fecal coliforms follows a pattern of initial wash-off from a surface source, consistent with wash-off from impermeable surfaces (most likely from animal deposition). This conclusion is supported by the much lower rates of fecal coliform discharge from the BCH site, which would be assumed to have much less animal activity.

The calculation of annual loads depends on many factors and can therefore only be roughly estimated at best. However, given that the concentrations were generally high throughout the storms, it appears reasonable as a first order approximation to extrapolate the annual load based on rainfall volume. Therefore, given that the measured storms contributed 4.9% of the total rainfall volume between 1950 and 2002, the annual fecal coliform load at this site is estimated as 2.4×10^{12} col . Accordingly, the average annual load per square meter of the total drainage area is estimated as 31 million colonies. The annual load per square meter of the impervious drainage area is estimated as 122 million colonies. See Table 20 for discharge and load comparison.

BCH

In contrast to site IWN, the fecal coliform concentrations showed a sharp first flush spike in concentration at the beginning of each storm. The first flush sample contained 3,600 col/100 ml of fecal coliform during Storm A and 1,000 col/100 ml during Storm F. During Storm C, the highest concentration was measured after 1 hour from the start of runoff (the rainfall rate at that time was 0.04 inches), which is consistent with the very slow start of the storm. Concentrations during the remainder of the storm were low, and in many samples below the detection limit. This concentration pattern is expected due to (a) the impermeable nature of the watershed and (b) the short storm sewer "system" (only a single man-hole and short pipe).

Extrapolating the fecal coliform annual load from the relative rainfall rate of the three storms, the annual fecal coliform load at this site is estimated as 4.7×10^9 colonies. The average annual load per square meter of the total drainage area is estimated as 8.6×10^5 colonies (using the number of storm approach). The annual load per square meter of the impervious drainage area is estimated as 8.9×10^5 colonies. See Table 20 for discharge and load comparison.

Results: Total Suspended Solids and Particulate Organic Carbon

IWN

The total suspended solids (TSS) concentrations were high during the first half of the two larger storms (Storms B and E) and decreased toward the end. Generally, the concentrations were higher with higher discharge rates. During Storm D with its comparatively low flow rate, the TSS concentrations remained high throughout the storm.

The particulate organic carbon (POC) concentrations followed the TSS concentrations closely. POC concentrations for all three storms consisted on average of 15% of the TSS concentration in the individual samples, ranging from on average 6% in Storm D to 21% in Storm B.

The annual TSS and POC loads are estimated as 418 kg and 62.2 kg, respectively. The average annual TSS and POC loads per square meter of the total drainage area are estimated as 5.44 grams and 0.81 grams, respectively. The average annual loads per square meter of the impervious drainage area are estimated as 21.15 grams and 3.15 grams, respectively. See Table 20 for discharge and load comparison.

BCH

Highest TSS and POC concentrations were measured at the beginning of the storms. POC concentrations followed the TSS concentration patterns closely. The average POC concentration for the three storms was 25%, ranging from an average of 15% during Storm F to 32% during Storm A.

The annual TSS and POC loads are estimated as 87 kg and 15 kg, respectively, extrapolating by rainfall volume. The average annual TSS and POC loads per square meter of the total drainage area were 15.85 grams and 2.64 grams, respectively. The average loads per square meter of the impervious drainage area were 16.45 grams and 2.74 grams, respectively. See Table 20 for discharge and load comparison.

Results: Phosphorus

IWN

Phosphorus concentrations were typically highest at the beginning of the storms. The maximum total phosphorus concentration measured was 0.84 mg/l; the maximum ortho-phosphate concentration was 0.79 mg/l. The average concentrations of ortho-phosphate relative to total phosphorus were 82% (Storm B), 71% (Storm D), and 54% (Storm E).

The annual total phosphorus and ortho-phosphate loads are estimated as 3.79 kg and 1.88 kg, respectively. The average annual total phosphorus and ortho-phosphate loads per square meter of the total drainage area are estimated as 0.049 grams and 0.024 grams, respectively (rainfall rate approach). The average loads per square meter of the impervious drainage area are estimated as 0.192 grams and 0.095 grams, respectively. See Table 20 for discharge and load comparison.

BCH

As with IWN, phosphorus concentrations were typically highest at the beginning of the storms. The maximum total phosphorus concentration measured was 1.06 mg/l; the maximum ortho-phosphate concentration was 1.04 mg/l. The average concentrations of phosphate relative to total phosphorus were 80% (Storm A), 58% (Storm C), and 17% (Storm F). Except for Storm F, the proportion of the total phosphorus attributable to ortho-phosphate is similar to IWN. At present there is no indication why Storm F would differ in phosphorus speciation compared to Storms A to E. Other storms had similar or lower total phosphorus discharges and there was no similar difference in dissolved inorganic nitrogen versus total nitrogen.

The annual total phosphorus and ortho-phosphate loads are estimated as 0.48 kg and 0.33 kg, respectively. The average annual total phosphorus and ortho-phosphate loads per square meter of the total drainage area are estimated as 0.087 grams and 0.059 grams, respectively (rainfall rate approach). The average loads per square meter of the impervious drainage area are estimated as 0.090 grams and 0.062 grams, respectively. These values are lower than the values from the Site IWN. See Table 20 for discharge and load comparison.

Results: Nitrogen

IWN

As with phosphorus, nitrogen concentrations were typically highest at the beginning of the storms. Nitrate was the largest nitrogen component, with the exception of three samples during Storm B where dissolved organic nitrogen was highest. Nitrate is a dominant nitrogen form in rainwater. However, the levels observed at this site are several fold higher than typical of rainfall and therefore indicate the pick-up of additional nitrate from the drainage basin prior to discharge. Nitrate could arise from the oxidation of organic nitrogen or urea from animal deposits or runoff of lawn fertilizers and even processed organic matter. About half of the total nitrogen discharge was found to be dissolved inorganic nitrogen (DIN), the combination of ammonium, nitrate, and nitrite. The sources of the DIN are generally the same. The contribution of organic nitrogen, although of a similar magnitude to the DIN, is likely to have less of an immediate impact on the receiving system, as it is not readily available for plant uptake and may be relatively refractory.

The estimated annual nitrogen loads are as follows:

- Nitrate and Nitrite: 9.40 kg
- Ammonia: 3.07 kg
- Dissolved Organic Nitrogen: 7.64 kg
- Particulate Organic Nitrogen: 6.55 kg

The average annual nitrogen loads per square meter of the total drainage area are estimated as follows:

- Nitrate and Nitrite: 0.122 grams
- Ammonia: 0.040 grams
- Dissolved Organic Nitrogen: 0.099 grams
- Particulate Organic Nitrogen: 0.085 grams

The average annual nitrogen loads per square meter of the impervious drainage area are estimated as follows:

- Nitrate and Nitrite: 0.475 grams
- Ammonia: 0.155 grams
- Dissolved Organic Nitrogen: 0.386 grams
- Particulate Organic Nitrogen: 0.331 grams

See Table 20 for discharge and load comparison.

BCH

As with phosphorus, nitrogen concentrations were typically highest at the beginning of the storms Dissolved organic nitrogen was the largest nitrogen component in Storms A and C. Nitrate was the largest component in Storm F. Site BCH was similar to IWN in its predominant nitrate flux. However, nitrate was a smaller contributor to the total flux than at IWN and was a smaller fraction of the DIN. This may result from a difference in nitrogen sources between the two sites and, to a lesser extent, of oxidation of the available ammonium at site BCH. Some support for the latter process is seen in that the DIN fluxes at the two sites are more similar than the nitrate fluxes. The total nitrogen fluxes from the two sites are relatively similar and the differences in the inorganic nitrogen constituents may merely represent a difference in the amount of digenesis that may be able to occur at each site prior to discharge.

The estimated annual nitrogen loads are as follows:

- Nitrate and Nitrite: 1.28 kg
- Ammonia: 0.93 kg
- Dissolved Organic Nitrogen: 3.59 kg
- Particulate Organic Nitrogen: 0.56 kg

The average annual nitrogen loads per square meter of the total drainage area were as follows (rainfall rate approach):

- Nitrate and Nitrite: 0.233 grams
- Ammonia: 0.169 grams
- Dissolved Organic Nitrogen: 0.654 grams
- Particulate Organic Nitrogen: 0.103 grams

The average annual nitrogen loads per square meter of the impervious drainage area were as follows (rainfall rate approach):

- Nitrate and Nitrite: 0.242 grams
- Ammonia: 0.175 grams
- Dissolved Organic Nitrogen: 0.679 grams
- Particulate Organic Nitrogen: 0.107 grams

See Table 20 for discharge and load comparison.

Results: Dissolved Oxygen

No specific trend was observed in the dissolved oxygen concentrations throughout the storms at either site. The stormwater was generally well oxygenated, except at the end of Storm E at site IWN. The lowest concentration measured was 4.9 mg/l. Dissolved oxygen concentrations were low in the catch basin at site BCH, as expected. Prior to Storm A, the concentration was 0.9 mg/l; prior to Storm C, the concentration was 5.0 mg/l. It appears that anaerobic conditions in the stormwater are not the cause of the ammonium levels observed in discharges. It may be that the ammonium merely represents nitrogen that has been mineralized and not yet nitrified to nitrate. It is also likely that a significant part of the ammonium may result from animal wastes deposited on the impermeable surfaces and then washed into the storm sewers. The role of groundwater in the measured DIN levels in the discharge waters is likely to be small. Groundwater nitrogen is predominantly as nitrate and little ortho-phosphate was observed. If the nitrogen and phosphorus was resulting from infiltration of groundwater, then the high ammonium and ortho-phosphate levels would not have been observed. All physical and biogeochemical factors indicate two systems dominated by surface water runoff, but with potentially different nutrient sources.

Results: Conductivity

For all storms, conductivity was highest at the beginning of all storms. Values measured in the field and in the laboratory were very similar. While conductivity appears to be a good indicator of first flush, there was not consistent agreement between contaminant levels and measured conductivity. This results from the fact that conductivity is dominated by dissolved constituents other than those measured as contaminants.

Results: Total Petroleum Hydrocarbons

Total Petroleum Hydrocarbons (TPH) were measured during the first three storms. None of the samples contained TPH above the detection limit. However, a small oil sheen was observed near the manhole at the site BCH at the beginning of storms.

Table 20. Total pollutant loads by storm and by annual estimates

	Fecal Coliform	TSS	PO4 *(as P)*	TP	NH4 *(as N)*	NO3+NO2 *(as N)*	DIN	DON	POC	PON
Units:	col x10^6	Grams								
Site IWN										
Storm B	40,794	8,928	61	81	96	281	376	286	1,455	186
Storm D	851	304	2	3	5	20	25	5	18	3
Storm E	76,344	11,261	29	102	50	161	210	83	1,576	132
Total	**117,989**	**20,494**	**92**	**186**	**150**	**461**	**611**	**374**	**3,048**	**321**
Annual Load (1)	**2,407,939**	**418,238**	**1,876**	**3,791**	**3,067**	**9,403**	**12,470**	**7,640**	**62,208**	**6,553**
Annual Load / m2 Total Drainage	**31.30**	**5.44**	**0.02**	**0.05**	**0.04**	**0.12**	**0.16**	**0.10**	**0.81**	**0.09**
Annual Load / m2 Impervious Area	**121.77**	**21.15**	**0.09**	**0.19**	**0.16**	**0.48**	**0.63**	**0.39**	**3.15**	**0.33**
Site BCH										
Storm A	86	247	13	13	29	32	61	139	67	6
Storm C	10.7	1,216	5	7	13	19	32	46	292	8
Storm F (3)	167.2	3,409	1	7	10	21	30	16	453	18
Total (2)	**264**	**4,872**	**18**	**27**	**52**	**72**	**123**	**201**	**812**	**32**
Annual Load (1)	**4,709**	**87,001**	**326**	**478**	**925**	**1,279**	**2,204**	**3,592**	**14,506**	**566**
Annual Load / m2 Total Drainage	**0.86**	**15.85**	**0.06**	**0.09**	**0.17**	**0.23**	**0.40**	**0.65**	**2.64**	**0.10**
Annual Load / m2 Impervious Area	**0.89**	**16.45**	**0.06**	**0.09**	**0.18**	**0.24**	**0.42**	**0.68**	**2.74**	**0.10**

1. Based on annual rainfall volume of 43.2 inches, and given that 5.6% of this volume fell during the three measured storms.
2. Storm F data were adjusted. The discharge volume measured with the flow meter was 2.5 times greater than the volume of rain that fell in the drainage area, based on the rain gage data.
3. The total loads utilize the *adjusted* data for Storm F.

Discussion

The stormwater investigation of the wetland study sites IWN and BCH supports the contention that detailed, site-specific studies are required to develop loading coefficients for general application over larger areas. The difference between the two sites is significant when trying to extrapolate from site-specific drainage basins to whole watersheds. Site IWN is primarily residential with significant vegetation and access for both wild and domestic animals. Site BCH is primarily a parking lot with little bordering vegetation. This difference in basin structure appears to be the dominant underlying cause of the differences in discharge and loading (see, especially, fecal coliform patterns) between the sites. However, even with the observed relatively large differences between the two sites, there were common trends in contaminant discharge. In fact, the major difference in nitrogen discharge was in the nitrogen forms rather than in the total nitrogen mass released per square meter of impermeable surface. The major contamination difference between the sites appears to be in bacterial loads with much higher loading from the residential watershed.

Except for Storm F, the two sites appear to yield similar total phosphorus and ortho-phosphate ratios, although the absolute amount of organic and inorganic phosphorus differed between the sites. There was clearly a higher total phosphorus loss (2x) from the impermeable area of site IWN, which may reflect the greater potential for plant matter to be washed into the storm drains at this site. The higher total phosphorus discharge per area of impermeable surface suggests a difference in organic matter composition, since the TSS and POC discharges are relatively similar at both sites. This inference is supported by the ratio of particulate C/N, which also suggests different organic matter sources between the sites.

The predominance of nitrate (56% and 38% of the total nitrogen fluxes at site IWN and site BCH, respectively) likely reflects the mobility of nitrate in soil and surface water systems. Nitrate also results from organic decay after microbial oxidation of released ammonium (i.e., nitrification). This nitrogen source is readily taken up by terrestrial and microbial autotrophy and is a major nitrogen form underlying the eutrophication of coastal waters. The high concentrations of nitrate suggest that runoff from the drainage area is the predominant source, since the nitrate concentrations were several times rainfall concentrations. The maximum concentrations at each site were higher at IWN, generally by a factor of 2. This may indicate a fertilizer source or another source associated with runoff from vegetated areas. This inter-site difference is also seen in the amount of ammonium relative to nitrate. Site IWN had little ammonium flux relative to nitrate (about 30%); at BCH, ammonium was about 70% of the nitrate flux. This result is further support for a difference in nitrogen source at the two sites and is consistent with runoff from vegetation at the IWN versus BCH. Further supporting evidence for a difference in sources comes from the POC/PON ratios. The much higher ratios at site BCH (10 to 35) versus site IWN (6 to 10) indicate that the particulate matter is of different quality, if not different source. Lower C/N ratios may indicate animal waste or fertilized plants (or even algae). The higher ratios can be from a variety of sources, including higher plants. Ratios of C/N are not conclusive and may result from the mixing of different particulate sources.

To gain some perspective on the results from this stormwater investigation, the data can be compared to other values reported from similar studies and the patterns in sites affected by stormwater and sites that are not can be examined.

For pollutants most commonly reported (total suspended solids, total phosphorous, and total nitrogen), the results of this investigation are favorably similar to other data available in the literature; with our nitrogen results being higher for both the residential and commercial land uses, but within range for the residential (Table 21). [The higher N values may be a function of more precise detection limits, which, when compiled cumulatively, generate higher values for the annual load.] This substantiation provides confidence for using these Massachusetts-specific land use loading coefficients—either by unit of drainage area or by impervious area.

Table 21. Comparison of annual loads by land use types for three pollutants

		TSS	**TP**	**TN**
Source	**Land use**	*kg/hectare*	*kg/hectare*	*kg/hectare*
CZM/Berger	Residential	**54.37**	**0.49**	**3.47**
URI [1]	Residential	**N/A**	**0.58**	**1.89**
Horner et al. [2]	Residential	**77.49**	**0.18**	**1.29**
FDER [3]	Residential	**100.34**	**0.80**	**1.93**
	mean	77.40	0.51	2.14
	stn. Dev.	22.98	0.25	0.93
		TSS	**TP**	**TN**
Source	**Land use**	*kg/hectare*	*kg/hectare*	*kg/hectare*
CZM/Berger	Commercial	**158.47**	**0.87**	**11.59**
URI [1]	Commercial	**N/A**	**0.32**	**2.03**
Horner et al. [2]	Commercial	**184.50**	**0.28**	**2.16**
FDER [3]	Commercial	**100.89**	**0.50**	**1.76**
	mean	147.95	0.49	4.38
	stn. Dev.	42.79	0.27	4.81

1. Kellogg, D.Q., L. Joubert; A. Gold, and J. Lucht. 1997. *Method for Assessment, Nutrient-loading, and Geographic Evaluation of Watersheds*. The URI Cooperative Extension Municipal Watershed Training Program. Kingston, RI.
2. Horner, R.R., J.J. Skupien, E. H. Livingston, and E. H. Shaver. 1994. *Fundamentals of UrbanRunoff Management: Technical and Institutional Issues.* Terrene Institute and U.S.Environmental Protection Agency. Washington DC.
3. Florida Department of Environmental Regulation. Summary of Land Use Loading Studies (see http://www.1000friendsofflorida.org/PUBS/stmarksGreen/apend4.asp).

It is well documented that wetlands possess certain characteristics that make them well-suited for pollutant removal (or temporary storage or absorbtion) (Mitsch and Gosselink, 1993; Hemmond and Benoit, 1988). In particular, the slowing and storage of rain and flood waters in wetlands allows for different biogeochemical processes to occur (e.g. settling, adsorption, absorption, biological uptake, and processing). Natural and created wetlands have been effectively utilized for the treatment of both wastewater (sewage) and stormwater (Corbitt and Bowen, 1994 and Bingham, 1994). The ability of a given wetland to retain, absorb, or transform specific pollutants can be compromised, though, when the assimilative capacity of the wetland is surpassed and the wetland actually becomes a net exporter of pollution (Brinson, 1988; Nixon, 1986). In addition, while a wetland may be performing water quality improvements by assimilating anthropogenic pollution, the effects of these pollutants on the ecology of the wetland and, therefore, on other wetland functions may be severe (Azous and Horner, 1997). While the effects of directly routing untreated stormwater to natural wetlands are not well documented, there is a strong body of literature reporting on effects of pollution, altered hydrology, and other adverse impacts to wetland biology and ecology (US EPA, 2002; Newton, 1989; Azous and Horner, 1997).

Of the 14 wetland study sites in this project, six have direct stormwater discharges from collected stormwater drainage networks (IWN, BTC, BCH, IPB, GGH, and DWR), and two have other types of routed stormwater through paved swale or drainage ditches (TCS and ETC). When examining the possible influence of stormwater on the biological condition of these sites, it is impossible to isolate stormwater as a single stressor or cause. As with many other assessment efforts, this cumulative impact paradigm becomes a major obstacle to the identification of specific sources of impairment. It is possible, though, to group sites by their stormwater discharge status (yes/no) and then to examine the results of the two biological indicators utilized in this project—the Plant Community Index and the Invertebrate Community Index (Figure 20). When the sites are grouped this way, the sites with stormwater discharges average 65 for the two combined indices, while the sites with no stormwater average 88. Further, when the distribution of the two biological index scores (averaged) are considered, seven of the eight sites affected by stormwater have scores below the mean of 75. There are other potential data analyses methods to try to sort out patterns like this, such as looking at the abundance of invasive species or the overall taxa richness of stormwater sites versus no stormwater.

Direct discharge of stormwater, as a pollution source, is comparatively deleterious. By design, stormwater bypasses the natural pollutant removal properties available from vegetated buffers and filter strips and instead routes the collected runoff through a network of catch basins to a discharge point. At this point, pollutant concentrations can be comparable to raw, untreated sewage (Bingham, 1994).

Addressing direct discharges of stormwater to wetlands, therefore, is a significant natural resource management issue. In 1997, Massachusetts became one of the first states to address this environmental problem with the issuance of its Stormwater Management Policy and inherent performance standards. When properly implemented through a host of regulatory programs, including especially the state's Wetland Protection Program, the Stormwater Management Policy prohibits the direct discharge of untreated (both for quality and quantity) stormwater to jurisdictional wetlands. This policy could be considered one of the single most powerful wetland protection efforts by the state in the last decade. Unfortunately, the policy applies only to current applications for new discharges under wetland and other state permits—it does not affect existing discharges. The extension of the National Pollutant Discharge Elimination System in 1999 (Phase II) to cover urban areas will help to address some of this unregulated direct discharge of stormwater. An urbanized area is a land area with a residential population of at least 50,000 and an overall population density of at least 1,000 people per square mile. Portions of many cities and towns in Massachusetts' coastal watersheds are covered under this program. The state does retain authority under its Clean Water Act and other regulatory bodies to require treatment or eliminate existing stormwater discharges, but there has been no consolidated effort to go after the multitudes of existing discharges. Until there is such an effort, the state will have to rely on pro-active mitigation efforts like those implemented through the state's Coastal Pollution Remediation (CPR) Program or the §319 Clean Water Grants Program.

[See: http://cfpub.epa.gov/npdes/stormwater/swphase2.cfm
http://www.state.ma.us/czm/cprgp.htm and
http://www.state.ma.us/dep/pao/news/3192002.htm]

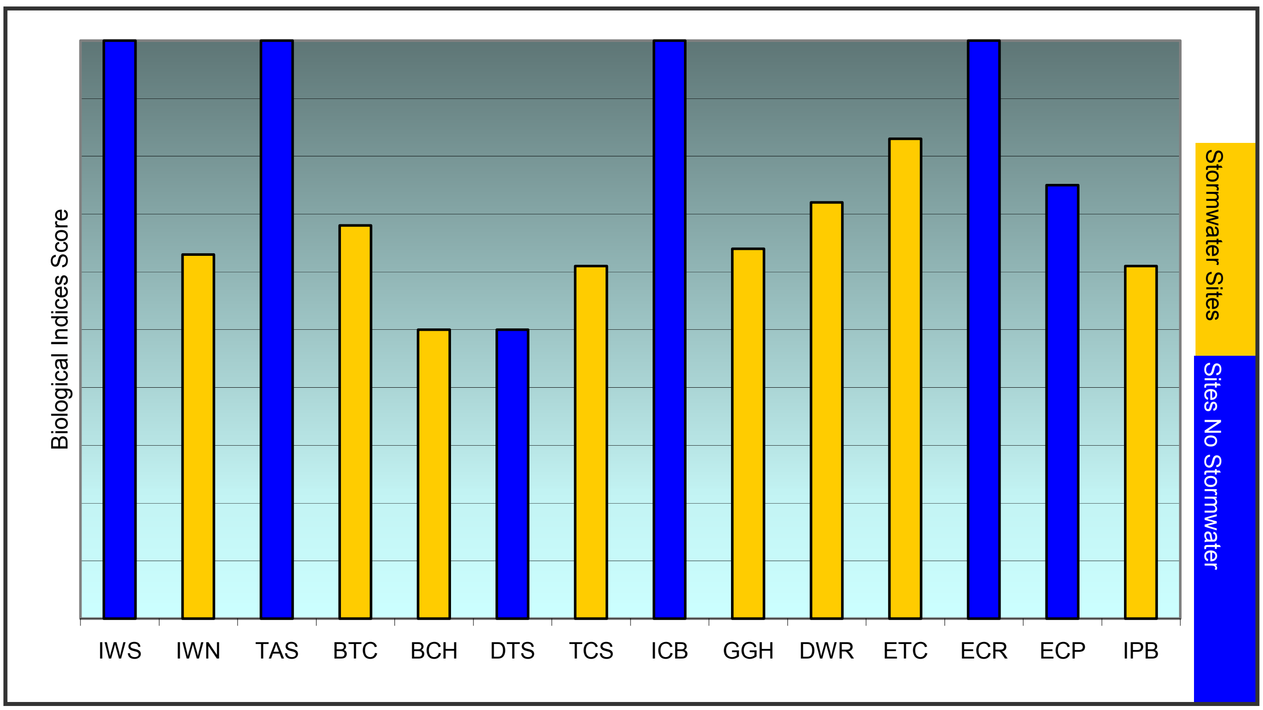

Figure 20. Biological index scores with sites grouped as affected by stormwater.

10. Data Examination

Index Totals and the Wetland Ecological Condition

Each of the indices described above represents an integrative score, summarizing the component attributes and characteristics of a biological assemblage or chemical parameters. As a quantitative value, the index provides a ranking of a wetland study site relative to the reference wetland condition. This point must be clearly emphasized and understood by those employing this and similar assessment approaches that rely on the use of the reference condition as the baseline for comparison. The output score, or rank, of any index, must be understood to be a relative score--relative only to the reference condition to which it was compared against. This means that one hypothetical study site with its own reference domain cannot be compared to another study site unless the same reference domain was employed for the analysis. In addition, caution must be exercised when evaluating and discussing the outputs of reference-based assessments. It may be difficult to make comparisons from one study site to another, outside of the reference context. For example, stating that study site X is more impaired than study site Y is only valid when qualified. It would be more appropriate to state that site X exhibits more impairment of its biological or physical components than site Y when compared to the reference domain as established by reference site Z.

All of the biological and chemical indices for a wetland assessment can be combined and integrated into a single cumulative score, the Wetland Ecological Condition. While the Wetland Ecological Condition score serves to integrate all of the ecological indicators and land use and habitat assessment methods, its quantitative output should be viewed as a general ranking score, and should be used in the proper context as described above.

Tables 22 and 23 display the final Wetland Ecological Condition scores for the freshwater and salt marsh wetland sites with all of the component indices and rapid assessment method scores. The Wetland Ecological Condition is simply derived--it is the weighted average of all the field-based ecological indicator protocols. To reflect the primary focus on biological assessment, the Plant Community Index (PCI) and Invertebrate Community Index (ICI) scores are weighted twice the values of the Water Chemistry Index (WCI) scores. Figures 21 and 22 graphically display the final index scores.

Table 22. Final scores for freshwater wetland sites

	IWS	TAS	IWN	TCS	BCH	BTC	DTS
Land Use Index	100	99	89	75	69	67	79
Habitat Assessment	90	82	82	70	64	58	68
Plant Community Index	100	100	67	50	38	79	46
Invertebrate Community Index	100	100	59	72	62	56	54
Water Chemistry Index	93	60	60	67	47	47	47
Wetland Ecological Condition	**99**	**92**	**62**	**62**	**49**		**49**

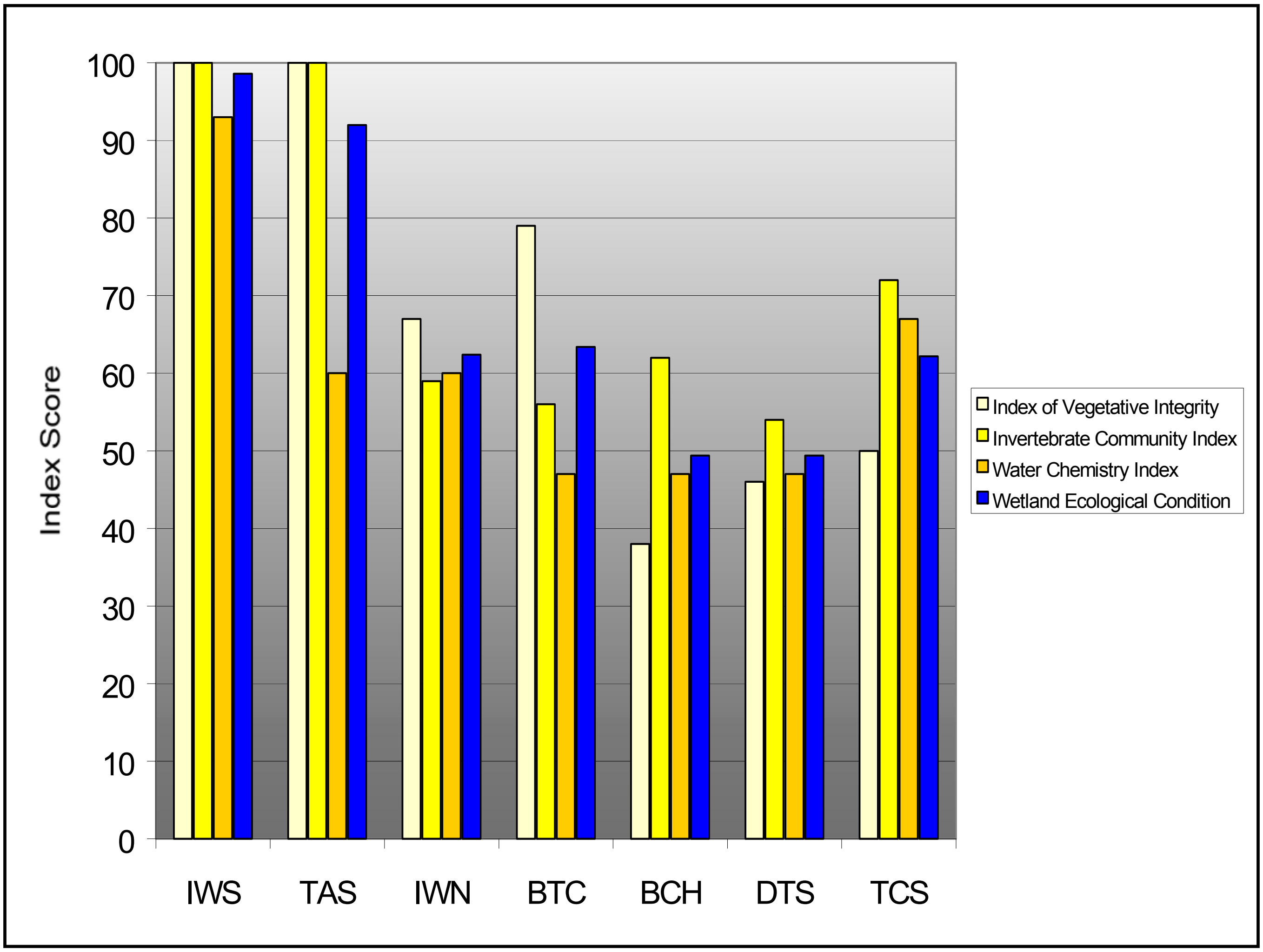

Figure 21. Final scores for freshwater wetland sites

Table 23. Final scores for salt marsh sites

	ICB	ECR	GGH	IPB	ETC	ECP	DWR
Land Use Index	94	87	78	66	72	71	78
Habitat Assessment	80	73	70	70	58	62	55
Plant Community Index	100	100	57	48	81	76	76
Invertebrate Community Index	100	100	70	74	85	74	67
Water Chemistry Index	80	67	60	67	87	60	80
Wetland Ecological Condition	**96**	**91**	**63**	**62**	**84**	**72**	**73**

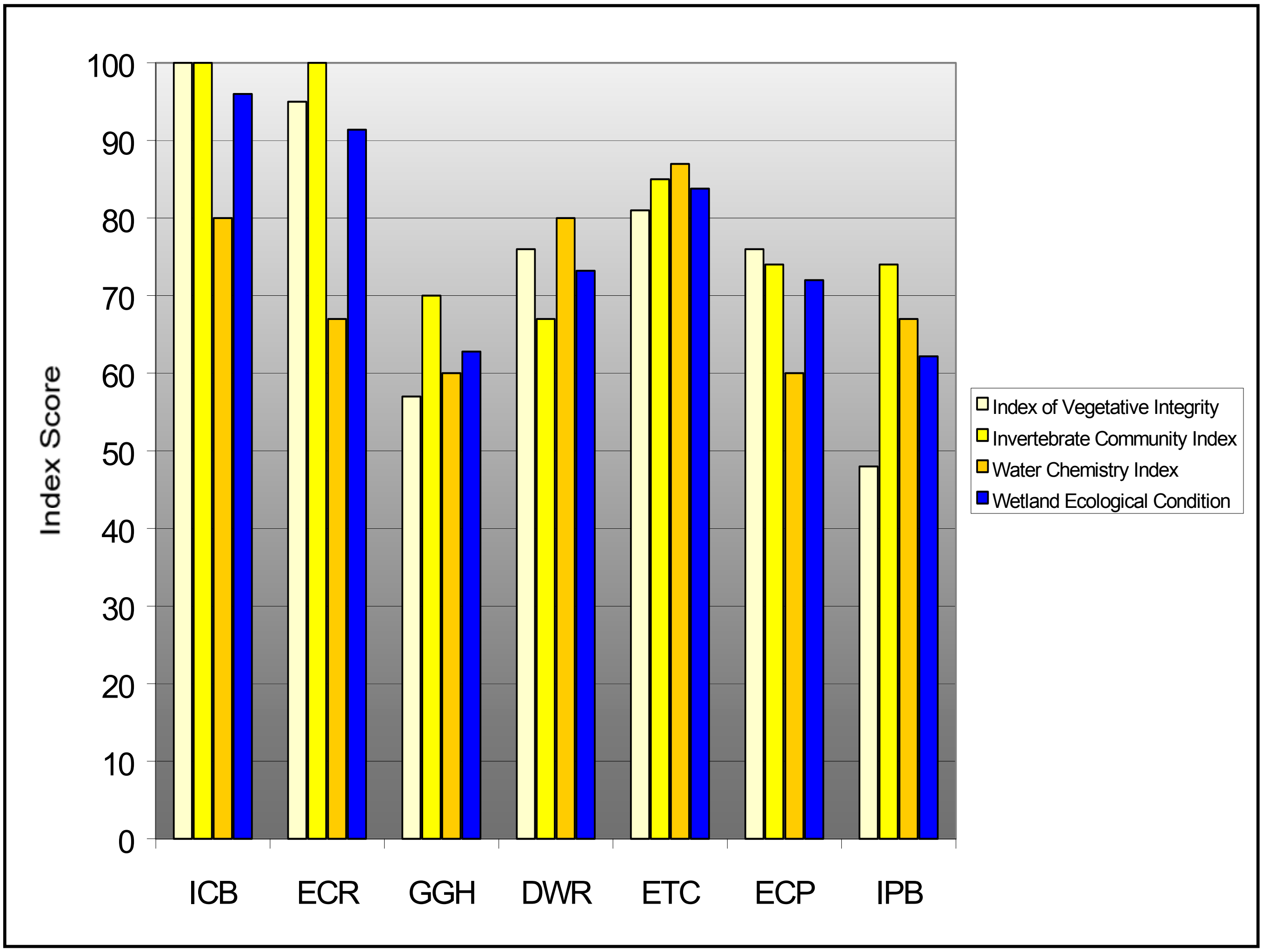

Figure 22. Final scores for salt marsh sites

Response and Relationship of Index Scores

The use of multi-metric indices for environmental assessment relies on the premise that biotic and abiotic conditions, parameters, or attributes respond to human (and natural) disturbances. As stated above, this Wetland Assessment Methodology incorporates a study design that depends on a minimally impacted reference condition as the baseline for comparison. To define the degree of human disturbance, or impact, this methodology employs a quantitative Land Use Index. The Land Use Index--as described in Section 4--examines the human land use types, practices, and intensities that occur in the landscape surrounding a given wetland study site. On-site field surveys are combined with GIS information, and land use coefficients to generate a score from 0 to 100. Sites that have little to no human development or detrimental activity score in the 90 to 100 range. These are considered to be minimally impacted and are considered to be reference condition candidates. Before final selection of a wetland as a reference, historical land uses and activities that are not currently present or evident should be considered.

As the base principle of this Wetland Assessment Method is that environmental indicators will respond to increasing human disturbance, it is therefore imperative to examine the different index results both in relation to human disturbance scale(s) and also in the context of one index to another. What are the relationships between the human disturbance scales and the biological multi-metric indices? What is the interdependence between separate biological indices? By computing a measure of association between these two groups, it is possible to examine their relationships.

Correlation coefficient analysis is a statistical technique used to compute the measure of association between two variables. A positive correlation is when an increase in one variable is accompanied by an increase in another; a negative correlation is an increase in a variable with a decrease in the other. The equation used to derive the correlation coefficient generates a value between +1.00 and -1.00. The size and sign of the correlation indicate the strength and nature of the relationship. Although there is no established principle for what constitutes a strong or weak relationship, general guidelines can be followed. A correlation coefficient of (+)1.00 indicates a perfect relationship--that is, every value for one variable co-varies identically with the value of another variable. Correlation coefficients above 0.75 indicate a strong relationship between variables, while coefficients from 0.40 to 0.75 imply a moderate relationship. For this analysis, coefficients below 0.40 are considered weak. It is important to remember that while variables may be strongly associated, they are not necessarily causal.

Based on a the correlation coefficient analysis of each of the individual index results as well as the Land Use Index and the Habitat Assessment scores, Table 24 (freshwater wetland sites) and Table 25 (salt marsh sites) were generated. Based on these tables, strong relationships exist between the Land Use Index and the overall Wetland Ecological Condition—that is sites with lower human disturbances (higher LUI scores) have higher ecological integrity. The correlation coefficient between LUI and WEC scores for freshwater wetland sites is 0.89 and 0.83 for salt marsh sites. Another strong association pattern is that between the Index of Vegetative Integrity and the Invertebrate Community Index, with freshwater sites displaying a correlation coefficient of 0.76 and salt marsh sites with a coefficient of 0.80.   In the comparison between all the index results for the freshwater wetland sites, most of the correlation coefficients are considered strong and only several showing moderate associations. The salt marsh sites matrix, on the other hand, reveals some moderate and weak associations, particularly stemming from comparisons involving the Water Chemistry Index.

Table 24. Correlation coefficients for freshwater wetland sites index results

	LUI	HA	IVI	ICI	WCI	WEC
Land Use Index	1.00					
Habitat Assessment	0.96	1.00				
Plant Community Index	0.74	0.62	1.00			
Invertebrate Community Index	0.80	0.75	0.76	1.00		
Water Chemistry Index	0.70	0.80	0.58	0.75	1.00	
Wetland Ecological Condition	0.89	0.85	0.89	0.93	0.84	1.00

Table 25. Correlation coefficients for salt marsh sites index results

	LUI	HA	IVI	ICI	WCI	WEC
Land Use Index	1.00					
Habitat Assessment	0.61	1.00				
Plant Community Index	0.79	0.24	1.00			
Invertebrate Community Index	0.72	0.64	0.80	1.00		
Water Chemistry Index	0.22	-0.26	0.45	0.29	1.00	
Wetland Ecological Condition	0.83	0.43	0.94	0.91	0.55	1.00

	Perfect	1.00
	Strong	0.75-1.00
	Moderate	0.40-0.74
	Weak	0.00-0.39

With such strong relationships between the human disturbance scale and the biological indicators, the question arises as to the predictive capacities of rapid and/or remote assessment techniques such as the Land Use Index. In fact, one of the recommendations of the Waquoit pilot project report was to continue statistical analysis to examine the observation that the rapid assessment techniques are able to predict wetland ecological and functional integrity. Similar to correlation, a regression analysis develops an equation that measures the proportion of the variability in one variable that is accounted for by variability in another and indicates to what extent one variable is influenced by another. Put another way, if the ecological integrity of a wetland site is considered to be dependent on the type and intensity of surrounding human land use, the question as to whether the Wetland Ecological Condition scores can be explained by Land Use Index results can be explored. Figure 23 displays the results from all 27 wetland sites assessed through this North Shore transfer project and the Waquoit pilot project combined. The linear relationship established by these two data sets clearly shows a distinct trend—as the Land Use Index decreases, so too does the Wetland Ecological Condition. The scatter of the data points around this line is the variability of this linear relationship, expressed through the r^2 value of 0.58. The lines below and above the linear best-fit line are the 95% confidence intervals—it is an indication of how good the estimation is for the predicted WEC values from known LUI values. As all but one of the actual data points falls within this confidence interval, the linear trend pattern established here is particularly strong. With future applications of the Wetland Assessment Method, additional data points will be added to this set, providing more insight into the strength of this trend. What is immediately evident is that based on this pattern, it may be possible to predict a wetland site's condition based on the surrounding land use—as measured by the Land Use Index.

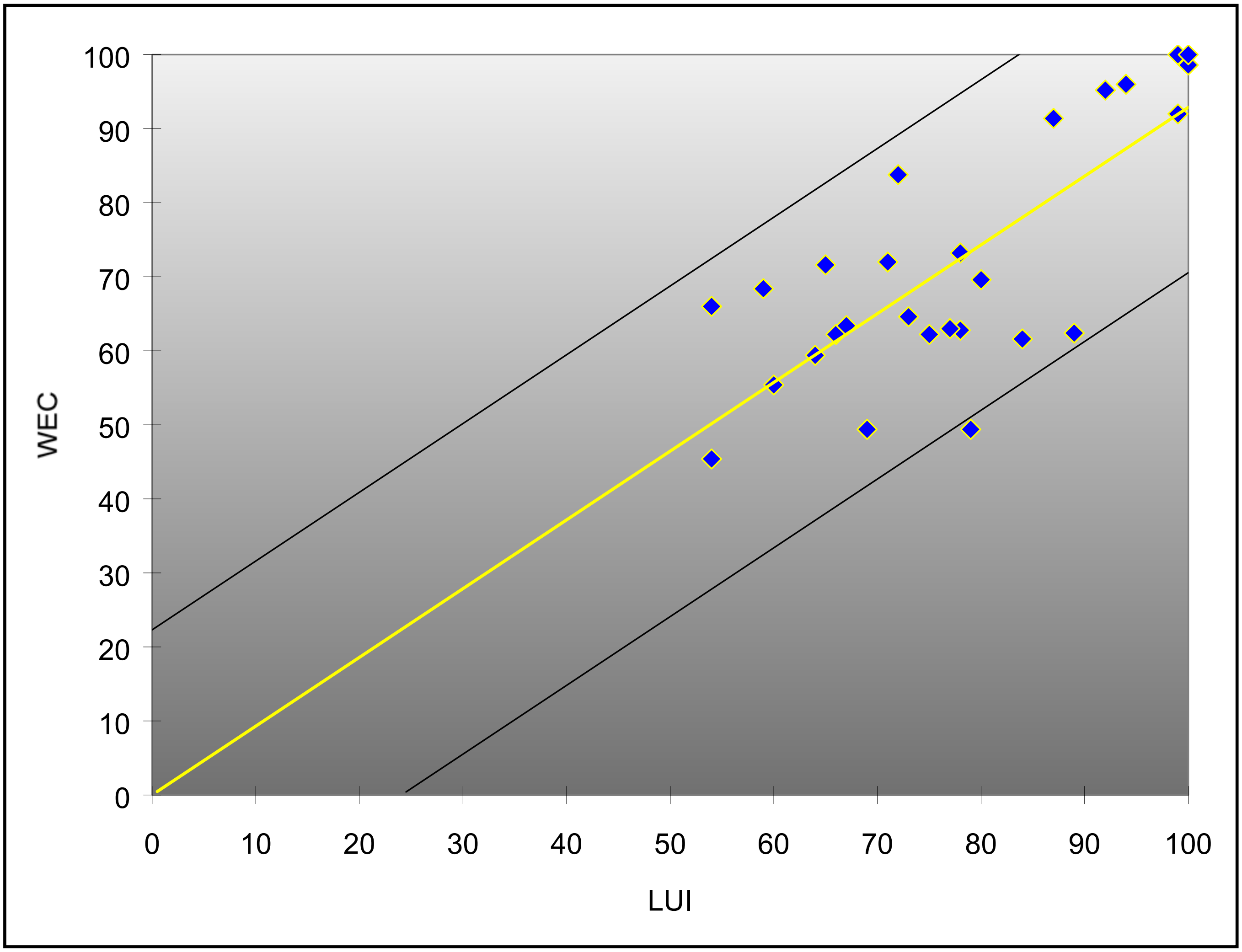

Figure 23. Trendline comparison of Land Use Index and Wetland Ecological Condition

11. Conclusion

In the conclusion of the Waquoit pilot project final report, several observations and recommendations stemmed from the development and first application of the Wetland Assessment Method. The over-arching conclusion was that the results of the pilot project were very promising, but that more applications of the assessment method were necessary, particularly in other regions and watersheds with different geology, hydrology, and land use patterns. Future applications of the approach would be fundamentally necessary to evaluate the comparative study design, sampling techniques, various metrics, their attributes, and other aspects of the methodology.

This transfer project on Massachusetts' North Shore in the Ipswich and North Coastal Watersheds enabled the project team to conduct a meaningful evaluation of the entire Wetland Assessment Method. Through this second application, it became evident that the fundamental design, approach, and techniques of the Wetland Assessment Method are sound and effective tools for measuring indicators of wetland integrity. What also became clear was that changes were necessary for different components of the Wetland Assessment Method. As demonstrated through the inclusion of some 13 separate recommended revisions in this report, the approach needed several significant and some minor alterations. The most noteworthy of these recommendations are those for establishing a consistent evaluation area within wetland study sites; modifying the vegetation and invertebrate sampling protocols; revising data analysis procedures for vegetation and invertebrates; and further evaluating the multi-metric data analysis structure for water quality parameters.

These recommendations have already been adopted by the protect team in current salt marsh assessment projects on Cape Cod and in new efforts to train volunteers in wetland assessment techniques. Nationwide focus on biological assessment of wetlands has expanded significantly, and through participation in both national and regional technical working groups, the authors have been able to share these and other results, obtaining important peer review and feedback. The following are just several of the groups and organizations that the authors have been active contributors to and collaborators in:

- National Monitoring and Assessment of Wetlands Workgroup: development of wetland bioassessment fact sheets and participation in the 1996 Wetlands: Biological Assessment and Criteria Development Workshop. (http://www.epa.gov/owow/wetlands/monitor/)
- Global Programme of Action; Coalition for the Gulf of Maine: development of the 1999 report *"Regional Standards to Identify and Evaluate Tidal Wetland Restoration in the Gulf of Maine"*.
- New England Biological Assessment of Wetlands Workgroup: one of three state projects funded in an effort to improve methods and programs used to assess the biological integrity of wetlands. (http://www.epa.gov/region1/eco/wetland/index.html)

- Wetland Health Assessment Toolbox (WHAT) Program: Salem Sound 2000 and Eight Towns and the Bay have cooperated in conjunction with UMass Extension Service, Massachusetts Bays National Estuary Program, and Massachusetts Office of Coastal Zone Management to run classroom and field workshops for over 70 volunteers.

Despite the recognized need for modifications to the Wetland Assessment Method, the North Shore Transfer Project was very successful in several areas. First, the fundamental design of the assessment approach developed in the Waquoit pilot project held sound for this second application. Reference-based comparative designs for wetland assessment have since been nationally recognized as a preferred approach. In taking the same basic protocols developed on southern Cape Cod and applying them to wetland sites on the North Shore, the authors were encouraged to witness results that demonstrate strikingly similar patterns of degradation linked with human land use and disturbance. Secondly, through the data analysis process, it became apparent that most, but not all, of the attribute metrics developed for the pilot project were valid and responsive when applied to the Ipswich and North Coastal watershed wetland study sites. Lastly, the statistical analysis of the North Shore data and results reveals important relationships and strong associations among different biological and chemical indicators as well as habitat and land use measures. These two separate wetland assessment projects have established a significant connection between the surrounding land use and sources of stressors and a wetland's ecological condition.

Finally, with continued applications of the Wetland Assessment Method, several important objectives and challenges remain. Again, as cited in the Waquoit pilot project report, the need to establish long-term datasets for wetland reference sites is imperative. To understand the response of systems to anthropogenic influence, it is first necessary to document and understand the natural variability of sites that are minimally affected by human disturbance. It is also important to see if the Wetland Assessment Method can be transferred to other applications, such as the investigation of tidal hydrological restrictions of salt marsh wetlands. Assessment work to document the effects and to track the response of tidal restoration projects is now underway on Cape Cod and the North Shore. Additional applications that should be pursued include the use of the assessment method to document changes in wetland ecological condition and surrounding land use over time, and the development of comprehensive inventories or sites in a discrete area. With each additional wetland assessment project, the database of surveyed taxa increases. The biological attributes for taxa existing in the database should be re-examined and attributes for new taxa developed. The continued development and verification of this biological attribute database is of critical importance to the effectiveness of the assessment approach.

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Appendix A: Land Use Index coefficients

Land Use Index coefficients

McConnell Land Use 37	Land Use Description	LUI Coefficient
1	Cropland	0.36
2	Pasture	0.45
3	Forest	1.00
4	Wetland	1.00
5	Mining, land disturbance	0.30
6	Open land	0.96
7	Participation recreation	0.85
8	Spectator recreation	0.75
9	Water recreation	0.85
10	Residential 0	0.20
11	Residential 1	0.36
12	Residential 2	0.58
13	Residential 3	0.75
14	Salt marsh	1.00
15	Commercial	0.20
16	Industrial	0.36
17	Urban open	0.85
18	Transportation	0.20
19	Waste disposal	0.10
20	Water	1.00
21	Woody perennial	0.70
22	No change	NA
23	Cranberry bog	0.36
24	Power lines	0.96
25	Sandy beach	1.00
26	Golf	0.55
27	Salt marsh	1.00
28	Irreg. flooded salt marshes	1.00
29	Marina	0.45
30	New ocean (accretion areas)	1.00
31	Urban public	0.85
32	Transportation facilities	0.20
33	Heath	0.85
34	Cemeteries	0.85
35	Orchard	0.45
36	Nursery	0.36
37	Forest wetland	1.00

Appendix B: Habitat Assessment forms

Freshwater Habitat Assessment form.

CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter

SCORING CRITERIA:	**5-6**	**3-4**	**1-2**	**0**	**SCORE**
LANDSCAPE Dominant land use	Forestry and open space	Low density residential or grazing	Medium-high density residential	Commercial, industrial, transportation	
%Impervious surface	< 5	5 - 10	11 - 20	> 20	
% Natural vegetation	> 50	30 - 50	10 - 29	< 10	
Ratio wetland/drainage basin area	> 10%	6 - 10%	2 - 5%	< 2%	
Possible major sources of pollution	No discernable source	Septic sewage effluent	Fertilizers and pesticides from gardens, golf, agriculture; sediments and de-icing salts	Industrial, commercial effluent, urban stormwater runoff	
WETLAND Water level fluctuation	Due to natural seasonal fluctuation	Some modification to natural hydrology through artificial control	Controlled by damming of the outlet	Fluctuation extreme and unseasonable due to dam release, or stormwater run-off	
Outlet restriction	No outlet restriction	Outlet restriction > 30'	Outlet restriction 5 - 30'	Outlet restriction <5'	
Rate of sedimentation	No evidence of sedimentation	Evidence of shallowing processes near inlets and storm water drains	Sand accumulation evident with some vegetation growing on bars	Sand accumulation smothering vegetation and forming bars	
Nature of sediments	Composed of equal quantities of gravel, sand, silt/mud, and organic matter	Predominantly silt/mud with organic material	Predominantly gravel, sand, with some silt/mud and organic material	Predominantly rocks, cobbles, gravel, and sand with no silt or organic matter	
Vegetation diversity	> 4 Cowardin classes	4 Cowardin classes	2 - 3 Cowardin classes	< 2 Cowardin classes	
% Presence of a vegetated buffer of 100' width	> 80	50 - 80	20 - 49	< 20	
Food sources	Abundance of macrophytes, algae, periphyton, CPOM, and FPOM	Some macrophytes, plus algae, periphyton, CPOM, and FPOM	Some algae and periphyton, CPOM, and FPOM	No macrophytes, no algae or periphyton, only some CPOM, and FPOM	
Degree of human activities in wetland: boating, trails roads, trampling, shoreline modification, solid waste	No human impact	Low level with minimal impact	Moderate level, erosion noticeable, vegetation degraded in places	High level, wetland severely degraded and neglected	
				TOTAL SCORE: **% (13 indicators, 78 maximum score) n/78 x 100**	

Salt marsh Habitat Assessment form.

CPOM = Coarse particulate organic matter, FPOM = Fine particulate organic matter

SCORING CRITERIA:	**5 - 6**	**3 - 4**	**1 - 2**	**0**	**SCORE**
LANDSCAPE Dominant land use	Forestry and open space	Low density residential or grazing	Medium-high density residential	Commercial, industrial, transportation	
%Impervious surface	< 5	5 - 10	11 - 20	> 20	
% Natural vegetation	>50	30 - 50	10 - 29	< 10	
Ratio wetland/drainage basin area	> 10%	6 - 10%	2 - 5%	< 2%	
Possible major sources of pollution	No discernable source	Septic sewage effluent	Fertilizers, pesticides from golf , agriculture; sediments and de-icing salts	Industrial, commercial effluent, urban stormwater runoff	
SALT MARSH Tidal fluctuation and degree of flushing	Natural tidal surges are unimpeded	Some modification to natural fluctuation due to artificial control	Controlled by constriction of the estuary outlet, or shoreline modification	Salt marsh cut off from normal tidal fluctuation	
Outlet restriction	No outlet restriction	Outlet restriction > 30'	Outlet restriction 5 - 30'	Outlet restriction < 5'	
Rate of erosion	No evidence of bank erosion	Evidence of bank erosion (mussels disturbed, grass thinned, slumping)	Bank eroding, processes well established	Severe bank erosion	
Nature of substrate at water/substrate interface	Composed of sand, silt/mud, or a mixture of both	Predominantly sand, or silt/mud with organic material	Predominantly organic peat with some sand and silt/mud	Predominantly rocks, cobbles, or peat	
Vegetation diversity	4 Cowardin classes	3 Cowardin classes	2 Cowardin classes	<2 Cowardin classes	
% Presence of a vegetated buffer of 100' width	> 80	50 - 80	20 - 49	< 20	
Food sources	Abundance of macrophytes, algae, periphyton, CPOM, and FPOM	Some macrophytes, plus algae, periphyton, CPOM, and FPOM	Some algae and periphyton, CPOM, and FPOM	No macrophytes, algae or periphyton, some CPOM, and FPOM	
Degree of human activities in salt marsh: boating, trampling, shoreline modification, waste	No human impact	Low level with minimal impact	Moderate level, erosion noticeable, vegetation degraded in places	High level, wetland severely degraded and neglected	
				TOTAL SCORE: **% (13 indicators, 78 maximum score) n/78 x 100**	

Appendix C: Plant Community Index attributes, metrics, and index scores

Freshwater wetland plant attributes and values

Genus	Species	Layer	PSL	Invasive	Opnt.	Wet	Flood	Nutrient
Acer	rubrum	sap/tree	1	0	0	0.50	0.8	0.34
Acer	saccharinum	sap/tree	1	0	0	0.82	0.6	0.78
Acorus	calamus	herb	0	0	1	1.00	0.6	0.34
Alnus	rugosa	sap/tree	1	0	0	0.91	0.6	
Alnus	sp.	sap/tree	1	0	0	0.91	0.6	
Asclepias	syriaca	herb	1	1	1	0.50	0.4	0.45
Bidens	connata	herb	0	0	1	0.91		
Bidens	coronata	herb	0	0	1	1.00		
Boehmeria	cylindrica	herb	0	0	0	0.91	0.4	0.34
Calmagrostis	canadensis	herb	0	0	0	0.91	0.6	0.34
Carex	crinata	herb	0	0	1	1.00	0.6	0.34
Carex	lurida	herb	0	0	1	1.00	0.6	0.56
Carex	sp.	herb	0	0				
Carex	stricta	herb	0	0	0	1.00	0.6	0.45
Carex	tribuloides	herb	0	0	1	0.91	0.8	0.45
Carex	pennsylvanica	herb	0	0	0	0.00	0.4	0.34
Celastrus	scandens	vine	1	0	1	0.09	0.6	0.56
Cephalnathus	occidentalis	shrub	1	0	1	1.00	1.0	0.34
Cicuta	bulbifera	herb	1	0	1	1.00	0.8	0.34
Cinna	arundinacea	herb	0	0	0	0.91	0.4	0.34
Clethra	alnifolia	shrub	1	0	1	0.60	0.4	0.34
Cornus	racemosa	shrub	1	0	1	0.50	0.4	0.34
Cornus	sericea	shrub	1	0	1	0.91	0.4	0.34
Dulichium	arundinaceum	herb	0	0	0	1.00	0.6	0.23
Eleocharis	obtusa	herb	0	0	1	1.00	0.6	0.34
Epilobium	coloratum	herb	0	0	1	1.00	0.4	0.34
Equisetum	fluviatile	herb	0	0	0	1.00	0.6	0.34
Erechtites	hieraciifolia	herb	0	0	1	0.18	0.4	0.34
Eriophorum	virginicum	herb	0	0	0	1.00	0.4	0.12
Eupatorium	purpureum	herb	1	0	0	0.82	0.4	0.56
Galium	tinctorium	herb	0	0	0	1.00	0.4	0.34
Galium	triflorum	herb	0	0	0	0.18	0.4	0.34
Hydrocotyle	americana	herb	0	0	0	1.00	0.4	
Hypericum	perforatum	herb	1	1	1	0.00	0.4	0.34
Hypericum	virginicum	herb	0	0	0	1.00	0.6	0.34
Ilex	verticullata	shrub	1	0	0	0.91	0.6	0.34
Impatiens	capensis	herb	0	0	1	0.82	0.4	0.45
Iris	pseudacorus	herb	0	0	1	1.00	0.6	0.67

Genus	Species	Layer	PSL	Invasive	Opnt.	Wet	Flood	Nutrient
Leersia	oryzoides	herb	0	0	1	1.00	0.8	0.56
Lonicera	tatarica	shrub	1	1	1	0.18	0.4	0.34
Ludwigia	palustris	herb	1	0	1	1.00	0.6	0.34
Lycopus	americanus	herb	1	0	1	1.00	0.6	0.34
Lysimachia	terrestris	herb	1	1	1	1.00	0.6	0.34
Lythrum	salicaria	herb	1	1	1	0.91	0.6	0.89
Mimulus	ringens	herb	1	0	0	1.00	0.6	0.34
Myrica	gale	shrub	1	0	0	1.00	0.6	0.34
Nuphar	variegatum	herb	0	0	0	1.00	0.6	0.56
Nyssa	sylvatica	sap/tree	1	0	0	0.50	0.6	0.23
Onoclea	sensibilis	herb	1	0	1	0.82	0.6	0.34
Osmunda	cinnamomea	herb	0	0	0	0.82	0.6	0.34
Phalaris	arundinacea	herb	0	1	1	0.91	0.8	0.45
Phragmities	australis	herb	1	1	1	0.82	0.6	1.00
Pilea	pumila	herb	0	0	1	0.82	0.6	0.34
Polygonum	sagittatum	herb	0	0	1	1.00	0.6	0.34
Prunus	pennsylvanica	sap/tree	1	0	1	0.18	0.4	0.34
Prunus	virginiana	sap/tree	1	0	1	0.18	0.4	0.34
Pyrus	coronaria	sap/tree	1	0	1			
Quercus	prinus	sap/tree	1	0	0	0.00	0.4	0.34
Rhamnus	frangula	shrub	1	1	1	0.50	0.4	0.56
Rhus	radicans	shrub	1	1	1	0.50	0.6	0.34
Rorippa	islandica	herb	0	0	1	1.00	0.6	0.34
Rosa	multiflora	shrub	1	1	1	0.18	0.4	0.34
Rosa	palustris	shrub	1	0	1	1.00	0.6	0.34
Rubus	allegheniensis	shrub	1	0	1	0.09	0.4	0.34
Salix	alba	sap/tree	1	1	1	0.82	0.6	
Salix	discolor	sap/tree	1	0	1	0.82	0.6	0.34
Sambucus	canadensis	shrub	1	0	1	0.71	0.4	0.45
Scirpus	cyperinus	herb	1	0	1	0.91	0.6	0.56
Smilax	rotundifolia	vine	1	0	1	0.50	0.4	0.34
Solanum	dulcamara	vine	1	1	1	0.40	0.4	0.34
Solidago	rugosa	herb	1	0	1	0.50	0.4	0.34
Solidago	gigantea	herb	1	0	1	0.82	0.4	0.34
Sparganium	americanum	herb	0	0	0	1.00	0.6	0.45
Sphagnum	palustre	herb	0	0	0	1.00	0.6	0.12
Spirea	latifolia	shrub	1	0	1			
Spirea	tomentosa	shrub	1	0	1	0.82	0.4	0.23
Symplocarpus	foetidus	herb	0	0	0	1.00	0.6	0.34

Genus	Species	Layer	PSL	Invasive	Opnt.	Wet	Flood	Nutrient
Thelypteris	thelypteroides	herb	0	0	1	0.91	0.6	0.34
Typha	angustifolia	herb	1	1	1	1.00	0.6	0.67
Typha	latifolia	herb	1	1	1	1.00	0.6	0.67
Ulmus	americana	sap/tree	1	0	1	0.71	0.6	0.45
Vaccinium	corymbosum	shrub	1	0	0	0.71	0.4	0.34
Verbena	hastata	herb	1	0	1	0.91	0.6	0.34
Viburnum	dentatum	herb	1	0	1	0.50	0.6	0.23

Salt marsh plant attributes and values

Genus	Species	PSL	Invasive	Opnt.	Wet	Nutrient	Salinity
Agalinis	maritime	0	0	0	0.91	0.23	0.60
Agropyron	pungens	0	0	0	0.09	0.67	0.40
Agrostis	stolonifera	1	0	1	0.82	0.34	0.40
Aster	subulatus	1	0	0			
Aster	tenuifolius	1	0	0			
Atriplex	patula	0	0	1	0.82	0.560	0.80
Baccharis	halimifolia	1	0	0	0.82	0.23	0.80
Carex	paleacea	0	0	0			
Carex	pennsylvanica	0	0	0	0.00	0.4	0.40
Chamaecyparis	thyiodes	1	0	0	1	0.12	0.20
Cuscuta	gronovii	1	0	1	0.82		0.40
Distichlis	spicata	0	0	1	0.91	0.34	1.00
Glaux	maritime	0	0	0	1.00	0.340	1.00
Iva	frutescens	1	0	0	0.91	0.34	0.80
Juncus	gerardii	0	0	0	0.91	0.34	1.00
Limonium	nashii	1	0	0	1	0.23	1.00
Lythrum	salicaria	1	1	1	0.91	0.6	0.40
Parthenocissus	quinquefolia	1	1	1	0.18	0.34	0.20
Phragmites	australis	1	1	1	0.82	1	0.60
Plantago	maritime	1	0	0	0	0.34	0.60
Puccinellia	maritime	0	0	0	1	0.34	0.80
Rosa	palustris	1	0	1	1	0.34	0.20
Rosa	rugosa	1	0	1	0.09	0.23	0.60
Salicornia	europaea	0	0	1	1		1.00
Salicornia	virginica	0	0	1	1		1.00
Salsola	kali	0	0	1	0.18		0.80
Scirpus	americanus	0	0	1	1.00	0.340	0.60
Solidago	sempervirens	1	0	1	0.82	0.34	0.80
Spartina	alterniflora	1	0	0	1	0.34	1.00
Spartina	patens	0	0	1	0.91	0.34	1.00
Suaeda	linearis	0	0	0	1		0.80
Teucrium	canadense	1	0	1	0.71	0.34	0.40
Toxicodendron	radicans	1	1	1	0.5	0.34	0.20
Triglochin	maritimum	1	0	1	1	0.34	1.00
Typha	angustifolia	1	1	1	1.00	0.6	0.60
Typha	latifolia	1	1	1	1.00	0.6	0.40

Freshwater Plant Community Index (PCI) metric and index scores

METRIC	IWS	TAS	Ref. Value	IWN	TCS	BCH	BTC	DTS	Stnd dev
Community Similarity	100.00	100.00	**100.00**	50.00	39.29	39.13	45.83	45.46	27.62
Score	**6**	**6**		**4**	**2**	**2**	**4**	**4**	
Taxa Richness	15	34	**25**	28	28	23	24	22	
Absolute Difference	10	9		3	1	2	1	3	3.76
Score	**6**	**6**		**6**	**6**	**6**	**6**	**6**	
Persistent Standing Litter	1.44	12.82	**7.13**	58.04	31.69	88.70	36.36	69.83	31.21
Score	**6**	**6**		**2**	**4**	**0**	**4**	**0**	
Invasive	1.44	36.96	**19.20**	40.70	40.98	68.23	16.92	70.13	24.94
Score	**6**	**6**		**2**	**2**	**0**	**4**	**0**	
Opportunistic	41.66	56.94	**49.30**	84.09	87.36	95.72	66.93	94.64	20.63
Score	**6**	**6**		**2**	**2**	**0**	**4**	**0**	
Wetness	89.11	78.96	**84.04**	88.57	72.34	86.11	83.90	89.03	
Ref./n x100 or n/ref.x100	94	94	**94**	95	86	98	100	94	4.27
Score	**6**	**6**		**6**	**2**	**6**	**6**	**6**	
Flood Tolerance	75.10	56.00	**65.55**	59.70	53.00	54.60	54.30	56.80	
Ref./n x100 or n/ref.x100	87	85	**86.36**	91	81	83	83	87	3.39
Score	**6**	**6**		**6**	**2**	**4**	**4**	**6**	
Nutrient Regime	29.57	46.80	**38.19**	49.80	50.90	60.30	46.70	62.20	
Ref./n x100 or n/ref.x100	77	82	**79.52**	77	75	63	82	61	8.27
Score	**6**	**6**		**4**	**4**	**0**	**6**	**0**	
PCI Score	**100.00**	**100.00**		**61.90**	**52.38**	**28.57**	**76.19**	**38.10**	

Freshwater Plant Community Index metric scoring criteria

Metric	0	2	4	6	SD
Community Similarity	≤15	16-43	44-71	≥72	28
Taxa Richness	≥13	9-12	5-8	≤4	4
Abundance PSL	≥70	39-69	8-38	≤7	31
Abundance Invasive	≥56	31-55	6-30	≤5	25
Abundance Opportunistic	≥92	70-91	50-70	≤49	21
Weighted Wetness	≤85	86-89	90-93	≥94	4
Weighted Flood Tolerance	≤79	80-82	83-85	≥86	3
Weighted Nutrient Regime	≤63	64-71	72-79	≥80	8

Salt marsh Plant Community Index (PCI) metric and index scores

METRIC	ICB	ECR	Ref. Value	GGH	IPB	ETC	ECP	DWR	STDEV
Community Similarity	100.00	100.00		60.00	69.23	90.91	71.43	76.92	15.85
Score	**6**	**6**		**2**	**4**	**6**	**4**	**4**	
Taxa Richness	12	10	**11**	20	13	11	14	13	
Absolute Difference	1	1		9	2	0	3	2	2.99
Score	**6**	**6**		**2**	**6**	**6**	**6**	**6**	
Persistent Standing Litter	34.65	21.04	**27.85**	8.98	73.49	28.85	64.97	27.12	23.53
Score	**6**	**6**		**6**	**2**	**6**	**2**	**6**	
Invasive	2.64	3.33	**2.99**	5.42	15.75	5.00	1.28	6.32	4.77
Score	**6**	**6**		**4**	**0**	**4**	**6**	**4**	
Opportunistic	45.73	41.35		15.37	73.95	46.42	72.20	33.44	20.73
Score	**6**	**6**		**6**	**2**	**4**	**2**	**6**	
Wetness	0.96	0.93	**0.95**	0.64	0.91	0.91	0.93	0.88	
N/Ref. x 100	99	98		67	96	96	98	93	11.20
Score	**6**	**6**		**0**	**4**	**4**	**6**	**4**	
Salinity Tolerance	1.00	0.96	**0.98**	0.80	0.90	0.90	1.00	0.87	
N/Ref. x 100	98	98		82	92	92	98	89	6.10
Score	**6**	**6**		**0**	**4**	**4**	**6**	**2**	
Nutrient Regime	0.34	0.34	**0.34**	0.45	0.51	0.51	0.34	0.49	
Ref./n x 100	100	100		76	67	67	100	69	16.53
Score	**6**	**6**		**2**	**2**	**2**	**6**	**2**	
PCI Score	**100.00**	**100.00**		**52.38**	**47.62**	**76.19**	**76.19**	**71.43**	

Salt marsh Plant Community Index metric scoring criteria

Metric	0	2	4	6	SD
Community Similarity	<52	52-68	68-84	<84	16
Taxa Richness	>9	6-9	3-6	<3	3
Abundance PSL	>83	59-83	35-59	<35	24
Abundance Invasive	>14	9-14	4-9	<4	5
Abundance Opportunistic	>86	66-86	46-66	<46	20
Weighted Wetness	<76	76-87	87-98	>98	11
Weighted Salinity Tolerance	<86	86-92	92-98	>98	6
Weighted Nutrient Regime	<66	66-82	82-98	>98	16

Appendix D: Invertebrate Community Index attributes, metrics, and index scores

Freshwater Invertebrate Community Index metric and index scores

METRIC/INDEX	IWS	TAS	IWN	TCS	BCH	BTC	DTS	Avg.
Total Number of Organisms	29.7	76	19	48.3	120	31	49	53.29
Total Taxa (Diversity)	4	12	15	13	17	13	12	12.29
EOT Richness	2	0	1	2	1	3	1	1.429
EOT/Chironomidae Ratio	0.06	-	19	0.2	0.13	8.5	66.7	13.51
% Tolerant/%Intolerant	0.25	11.1	32.27	1.28	78.94	22.7	25.9	24.64
Family Biotic Index	5.93	6.3	7.05	6.39	8.14	7.6	7.37	6.969
% Contribution Dominant Family	93	51	33	57	50	34.4	84	57.49
Other Odonata/Coenagrionidae Ratio	33.3	0	633.3	0	0	500	0	166.7
% Contribution Selected Groups:								
Oligochaeta	0	0.4	3.5	18	2.5	0	84	15.49
Hirudinea	0	0	0	0	1.4	0	0	0.2
Gastropoda	0	16	7	0	0.8	25.8	0	7.086
Pelecypoda	0	18	28	4.8	4.7	0	0.7	8.029
Amphipoda	0	7.5	1.8	57	50	34.4	0	21.53
Isopoda	1.1	2.6	3.5	0.7	26	3.23	0	5.304
Hydracarina	0	1.3	1.8	0	0	1.08	0	0.597
Colembola	0	51	0	0.7	1.4	0	0	7.586
Ephemeroptera	0	0	0	2.1	0	0	0	0.3
Odonata	1.1	0	33	0	0	16.1	0	7.171
Hemiptera	0	0	7	0	0.8	1.08	0	1.269
Homoptera	0	0	0	0	0	0	0	0
Coleoptera	0	2.2	7	2.1	4.4	14	6.8	5.214
Megaloptera	0	0	0	0	0	0	0	0
Trichoptera	4.5	0	0	0.7	0.8	2.15	1.4	1.364
Lepidoptera	0	0	0	0	0	0	0	0
Diptera	93	0	7	14	6.6	2.15	7.5	18.61
Others	0	0	0	0	0.6	0	0	0.086
Community Taxa Similarity Index	100	100	29.68	26.23	21.53	20.53	11.03	
Community Trophic Similarity Index	100	100	30.75	53.25	48.25	46.25	37.25	
INVERTEBRATE COMMUNITY INDEX	100	100	59	72	62	56	54	

Freshwater wetland Invertebrate Community Index metric scoring criteria

Metric	6	4	2	0
Total Organisms	>90	70-90	50-69	<50
Total Taxa Richness	>90	70-90	50-69	<50
EOT Richness	>90	70-90	50-69	<50
EOT/Chironomidae Ratio	>80	65-80	26-64	<25
Family Biotic Index	>90	70-90	40-69	<40
%Tolerant / %Intolerant	>80	65-80	25-64	<25
%Contribution Dominant Family	>70	50-70	30-49	<30
OtherOdonata / Coenagrionidae Ratio	>80	65-80	25-64	<25
% Chironomidae	>90	70-90	50-69	<50
% Oligochaeta	>90	70-90	50-69	<50
Community Taxa Similarity Index	>64	50-64	35-49	<35
Community Trophic Similarity Index	>64	50-64	35-49	<35

Salt marsh Invertebrate Community Index metric and index scores

METRIC/INDEX	ICB	ECR	GGH	IPB	ETC	ECP	DWR	Avg.
Total Number of Organisms	31.33	36.33	25.33	2.33	32.33	47.3	19.67	27.81
Total Taxa Diversity	20	8	4	5	20	12	5	10.57
% Contribution Dominant Group	40.43	71.56	75	42.9	28.87	39.4	45.76	49.13
% Contrib. Dominant Feeding Group	66.96	71.56	77.64	42.9	35.04	76.1	45.76	59.41
% Common/% Rare Ratio	0.05	0.14	1	0	0.11	0.33	0.67	0.33
% Contribution Selected Groups:								
Nemerta	0	0.92	0	0	0	2.82	0	0.53
Captelida	40.43	0	21.05	14.3	6.19	29.6	5.08	16.66
Cossurida	0	0	0	0	0	0	0	0.00
Ctenodrilla	3.19	0	0	0	0	0	0	0.46
Eunicida	3.19	0	0	0	2.06	1.41	5.08	1.68
Orbiniida	1.06	0	0	14.3	1.03	0	0	2.34
Sabellida	0	0	0	0	0	0	0	0.00
Spionida	20.21	0	0	0	3.09	39.4	1.69	9.20
Opheliida	0	3.67	0	0	0	2.11	0	0.83
Phyllodocida	13.83	71.56	75	42.9	24.74	16.9	45.76	41.52
Terebellida	0	0	0	0	0	0	0	0.00
Unknown Polychaeta	1.06	0	0	0	0	0	0	0.15
Amphipoda	1.06	8.26	1.32	0	13.4	1.41	42.37	9.69
Tanaidacea	0	0	0	0	0	1.41	0	0.20
Gastropoda	6.38	0	0	28.6	5.15	0	0	5.73
Decapoda - Shrimps	2.13	11.93	0	0	28.87	0	0	6.13
Decapoda - Crabs	2.13	0	2.63	0	0	0	0	0.68
Isopoda	0	0	0	0	1.03	0	0	0.15
Pelycypoda	4.26	3.67	0	0	14.43	1.41	0	3.40
Thoracica	0	0	0	0	0	0	0	0.00
Other Groups	1.06	0	0	0	0	3.52	0	0.65
% Captelida Plychaeta	40.43	0	21.05	14.3	6.19	29.6	5.08	16.66
% PaLaemonedae Shrimps	2.13	11.93	0	0	28.87	0	0	6.13
Community Taxa Similarity Index	100	100	65.29	60.7	54.99	54.3	55.73	
Community Trophic Index	100	100	65.86	74.7	70.13	59.5	69.57	
Invertebrate Community Index	100	100	70	74	85	74	67	

Salt marsh Invertebrate Community Index metric scoring criteria

Metric	6	4	2	0
Total Organisms	>90	70-90	50-69	<50
Total Taxa Richness	>90	70-90	50-69	<50
% Contribution Dominant Taxonomic Group	>70	50-70	30-49	<30
% Contribution Dominant Trophic Group	>70	50-70	30-49	<30
% Abundant/% Rare	>80	65-80	25-64	<25
% Capitellida polychaete worms	>90	70-90	50-69	<50
% Palaemonedae shrimp	>90	70-90	50-69	<50
Community Taxa Similarity Index	>64	50-64	35-49	<35
Community Trophic Similarity Index	>64	50-64	35-49	<35

Appendix E: Water Chemistry Index metrics and index scores

Freshwater wetland Water Chemistry Index metric and index scores

	IWS	TAS	Ref	IWN	TCS	BCH	BTC	DTS	StDev
Specific Conductivity	80.57	335.10	207.84	363.90	350.76	406.90	577.86	539.43	*162.03*
Score	**6**	**4**		**4**	**4**	**2**	**0**	**0**	
Fecal Coliform	25.67	150.00	87.84	189.00	150.00	150.00	98.00	117.67	*52.62*
Score	**6**	**2**		**2**	**2**	**2**	**4**	**4**	
Phosphorous	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	*0.00*
Score	**4**	**4**		**4**	**4**	**4**	**4**	**4**	
Ammonia	0.18	0.47	0.33	0.36	0.25	0.33	0.11	0.59	*0.17*
Score	**6**	**4**		**4**	**6**	**4**	**6**	**2**	
Nitrate/Nitrite	0.39	0.54	0.47	0.57	0.49	0.92	1.58	0.47	*0.42*
Score	**6**	**4**		**4**	**4**	**2**	**0**	**4**	
sub	28	18		18	20	14	14	14	
WCI	**93.33**	**60.00**		**60.00**	**66.67**	**46.67**	**46.67**	**46.67**	

Freshwater wetland Water Chemistry Index metric scoring criteria

Metric	**0**	**2**	**4**	**6**	StDev
Specific Conductivity	>532	371-532	209-370	<208	162
Fecal Coliform	>195	142-194	89-141	<88	53
Phosphorous	>0.20	0.11-0.19	0.03-0.10	<0.02	0.00
Ammonia	>0.68	0.51-0.67	0.34-0.50	<0.33	0.17
Nitrate/Nitrite	>1.32	0.90-1.31	0.48-0.89	<0.47	0.42

Salt marsh Water Chemistry Index metric and index scores

	ICB	ECR	ref	GGH	IPB	ETC	ECP	DWR	StDev
Salinity	10.34	24.81	17.58	35.66	0.12	31.83	11.56	21.80	*11.79*
Score	**0**	**4**		**6**	**0**	**6**	**0**	**2**	
Fecal Coliform	2.00	121.33	61.67	3.67	8.00	3.67	37.00	38.33	*43.03*
Score	**6**	**2**		**6**	**6**	**6**	**6**	**6**	
Phosphorous	0.09	0.08	0.09	0.31	0.12	0.12	0.08	0.08	*0.08*
Score	**6**	**6**		**0**	**4**	**4**	**6**	**6**	
Ammonia	0.14	0.33	0.24	0.86	0.22	0.37	0.37	0.28	*0.23*
Score	**6**	**4**		**0**	**6**	**4**	**4**	**4**	
Nitrate/Nitrite	1.14	1.77	1.46	0.35	1.74	0.26	2.27	0.60	*0.79*
Score	**6**	**4**		**6**	**4**	**6**	**2**	**6**	
sub	24	20		18	20	26	18	24	
WCI	**80.00**	**66.67**		**60.00**	**66.67**	**86.67**	**60.00**	**80.00**	*10.69*

Salt marsh Water Chemistry Index metric scoring criteria

Metric	**0**	**2**	**4**	**6**	StDev
Salinity	<18	19-23	27-24	>28	12
Fecal Coliform	>151	108-150	63-107	<62	43
Phosphorous	>0.26	0.18-0.25	0.10-0.17	<0.09	0.08
Ammonia	>0.71	0.48-0.70	0.25-0.47	<0.24	0.23
Nitrate/Nitrite	>3.05	2.26-3.04	1.48-2.25	<1.46	0.79